The Golden West: Influential Innovation from the San Francisco Region Revealed in Patent Records

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This Article interprets San Francisco Region innovation using patent records and associated "crowdsourced" information on patent influence. Information on the production of patented advances and related patent citations is used to characterize several distinctive features of innovation from the San Francisco Region, including the exceptional influence of San Francisco innovation on subsequent technology development, the emphasis on San Francisco innovators on technology fields with high value growth, and the reliance of San Francisco innovators on unusually large innovation teams. In addition to illuminating several key features of the San Francisco innovation, this study illustrates the value of patent records as sources of previously untapped information on innovation processes and regional innovation strengths.

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I. INTRODUCTION

The San Francisco Region—extending from the City of San Francisco south to "Silicon Valley" and east to include recent innovation centers in the East Bay—is a distinctively successful innovation center and a driving force behind the U.S. economy.[1] The Region is often considered the epicenter of global innovation.[2] However, the innovation features and processes accounting for the Region's technical success are still poorly understood.[3] Other regions hope to emulate San Francisco's success but have little clear information on what innovation characteristics to replicate.[4] If the factors behind San Francisco's innovation differences remain hidden, efforts elsewhere to emulate San Francisco's innovation success are likely to be both wasteful and futile.

This Article expands understanding of local features of San Francisco innovation by interpreting technical advancement there through the lens of patent records. It identifies several features that distinguish innovation in the San Francisco Region from counterparts elsewhere. Beyond recognizing—as have other studies[5]—that San Francisco innovators produce advances at remarkable rates, this Article uses patent records to show that San Francisco innovators work in fields with particularly large value growth and achieve unusually high influence on subsequent technology development in these key fields.

Patent records are important sources of information for innovation process studies for a number of reasons. First, patents describe especially important innovations constituting intellectual outliers in their

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1. *See, e.g.,* Richard Florida, *San Francisco's Increasing Dominance Over U.S. Innovation*, CITYLAB (May 25, 2016), http://www.citylab.com/life/2016/05/san-franciscos-increasing-dominance-over-us-innovation/484199/.

2. *See* Frank Holmes, *San Franciso Named a Global Leader in Disruptive Innovation*, FORBES (June 29, 2017, 10:23 AM), http://www.forbes.com/sites/greatspeculations/2017/06/29/san-francisco-named-a-global-leader-in-disruptive-innovation/#6bb62a0424a2.

3. A number of analysts have sought to identify the reasons for the San Francisco Region's exceptional success in developing and commercializing new technologies. *See, e.g.,* Barry Jaruzelski, *Why Silicon Valley's Success Is So Hard To Replicate*, SCI. AM. F. (Mar. 14, 2014), http://www.scientificamerican.com/article/why-silicon-valleys-success-is-so-hard-to-replicate/ [*hereinafter* Jaruzelski, SAF]; *see also* BARRY JARUZELSKI ET AL., BAY AREA COUNCIL ECON. INST. & BOOZ & CO., THE CULTURE OF INNOVATION: WHAT MAKES SAN FRANCISCO BAY AREA COMPANIES DIFFERENT? (Mar. 2012), http://www.bayareaeconomy.org/files/pdf/CultureOfInnovationFullWeb.pdf.

4. Some of these efforts to emulate the research and technology development dynamics of the San Francisco Region have been massive but still lacked successful results. According to Barry Jaruzelski (writing in 2014):

> Countries around the world are doing their best to copy [Silicon Valley's] magic. Take China, where companies in a variety of industries have boosted their research and development spending by an average of 64% every year for the past five years, and the Beijing government is making huge investments in the country's university system. The hope is that such an infusion of resources will generate a Silicon Valley–style symbiosis between industry and the research sector. The effort has been massive, but so far the results are anything but.

Jaruzelski, SAF, *supra* note 3.

5. *See, e.g.*, Florida, *supra* note 1; Holmes, *supra* note 2.

fields. To qualify for patents (and thereby enter patent data records) advances must not only be new but must be nonobvious, meaning they involve at least some features that would not have been obvious innovations in the eyes of most parties in the same innovation design communities.[6] Nonobvious outliers of this sort can move fields in new directions and serve as the bases for commercially significant new products and product features.[7] For this reason, patented advances are often important milestones in technology development; information on how these are generated indicates whether innovators in a city or region tend to be pioneers or followers in technology development.

Second, patent records accumulate information on the heritage of new technologies and the influence of past advances on the shaping of newer advances. This information on invention heritage and influence is captured through patent citations.[8] Parties applying for patents on new advances must cite earlier patents that describe innovations that are similar to the new advances.[9] As a result, citations in recent patent applications (and the resulting patents) point to prior patented advances that current innovators recognize as important in shaping their fields and that define the background of their current advances. By analyzing how often past patents are cited in more recent patent applications, it is possible to identify past advances with conceptual relationships to many recent advances. The resulting information not only records the heritage of the recent advances, it also identifies past advances with especially large influence on later technology development. This information is a "crowdsourced" characterization of technology development, with recent patent applicants serving as the relevant crowd providing rating information on invention heritage and influence.[10]

Innovation rating information of this sort can be used for a variety of innovation studies. It is used here to examine some of the distinctive features of San Francisco innovation. By comparing citation levels for inventions produced by San Francisco innovators with levels for innovations produced in other locations, we can see concrete evidence of

6. *See* 35 U.S.C. § 103 (2012); Graham v. John Deere Co., 383 U.S. 1, 14 (1966).

7. *See Graham*, 383 U.S. at 14.

8. Recent patent applicants citing earlier advances indicate that knowledge of the earlier advances shaped the content or background of the recent applicants' work, thereby indicating that the earlier advances "influenced" the recent work and are part of the "heritage" of that work.

9. *See* 37 C.F.R. § 1.56 (2016).

10. *See Crowdsourcing*, MERRIAM-WEBSTER, http://www.merriam-webster.com/dictionary/crowdsourcing (defining "crowdsourcing" as "the practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people") (last visited Oct. 23, 2017).

the significantly greater influence of San Francisco innovations over advances produced elsewhere.

This Article uses citation levels and other information from patent records to evaluate distinctive features of San Francisco innovation. The study described here found that innovators in the San Francisco Region engage in exceptionally high levels of collaborative research,[11] tend to produce advances in high growth fields,[12] appear to have especially extensive influence on subsequent research activities,[13] and create advances frequently found valuable by acquirers and transferred in patent assignment transactions.[14] Regression analyses controlling for differences in innovation technology types, invention complexity, the extent of inventor collaboration, and patent application prosecution delays showed that, across innovatons differing in these characteristics, innovations from the San Francisco Region gained significantly more attention in later research and had substantially more projected value growth than innovations elsewhere.[15] Overall, San Francisco innovations appear to have significantly greater value that those from other sources[16] and are much more rarely neglected than those produced elsewhere.[17]

The study also evaluated local variations in innovations and innovators within the San Francisco Region. The study found differences both in numbers of inventions across cities within the region (as assessed in terms of numbers of patented advances for particular cities and numbers per capita)[18] and in the influence of advances from particular cities (as measured by the aggregate citations received by advances from cities and of the aggregate citations per capita).[19] Additional analyses found substantial variations in the distribution of inventors across cities within the San Francisco Region, with large differences in numbers of inventors and numbers of inventors per capita.[20] Technology innovation specializations were identified for communities within the San Francisco Region, with most of the production of certain technologies concentrated in narrow geographic areas within the region.[21]

11. *See infra* Section IV.A.
12. *See infra* Section IV.D.
13. *See infra* Sections IV.B., IV.E.
14. *See infra* Section IV.F.
15. *See infra* Section IV.H.
16. *See infra* Section IV.C.
17. *See infra* Section IV.G.
18. *See infra* Section V.A.1.
19. *See infra* Section V.C.
20. *See infra* Section V.A.2.
21. *See infra* Section V.B.

Taken together, the findings of this study add to our understanding of both why San Francisco innovation has been exceptionally successful and where, within the region, the greatest success has prevailed. The techniques used here provide useful tools for the future in locating regions producing "hot tech"—advances receiving high attention and having likely future value—as well as possibly pointing to particular high value advances early in the life of the advances.[22]

Part II of this Article explains why patent records are important sources of data for analyzing local innovation features. Part III of the Article highlights previous studies of San Francisco innovation and describes how they relate to the analyses presented in this Article. Part IV quantifies several distinctive innovation features of the San Francisco Region compared to areas outside the Region. Part V turns inward to evaluate differences between innovation in georgraphic areas within the San Francisco Region. Part VI suggests ways to extend the analytic techniques used here to conduct further studies of local innovation features. Part VII of the Article concludes with comments on some of the implicaitons of the findings of this study.

II. USING PATENT RECORDS TO INTERPRET LOCAL INNOVATION

This Article relies on several types of innovation evidence from patent records. Innovators in the San Francisco Region—including innovators as far south as "Silicon Valley" and in the East Bay areas that include Berkeley and Fremont—have enormous impacts on technology advancement and the U.S. economy.[23] Patent records document the types of advances being produced in the San Francisco Region and the favorable response innovators worldwide have had to those advances.[24] The combination in patent records of technology "census" information (as recounted in the descriptions of patent advances and the aggregate counts of various types of advances) and influence ratings (derived from the citations to advances provided by inventors seeking patents on more recent innovations) create a rich set of sources for characterizing both the features and importance of San Francisco innovation.

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22. *See infra* Section VI.D.

23. *See, e.g.*, Florida, *supra* note 1.

24. The patented advances themselves are described in the texts of patent covering the advances, while the reactions of inventors to previously patented advances can be assessed from the aggregated levels of citations of inventors in patent applications to the work of earlier inventors. Both of these uses of patent sources are described in more detail in this Part.

A. *Patent Records as Portraits of Technology Development Milestones*

Patent records supply important information for interpreting innovation[25] in part because they describe particularly significant types of technology advances. The advances addressed in the patent records include many important milestones in technology development.[26] Patents capture information about discoveries that are technology outliers, that is, innovations that are not only new but that are distinct departures from prior technology.[27] To qualify for a patent, an advance must be more than just an obvious extension of prior technology in the eyes of well-informed parties in the same technical field.[28] Patent examination processes within the United States Patent and Trademark Office (USPTO) ensure that advances generally only receive patents when the advances meet these high standards as technology outliers.[29] While the commercial importance of a patented advance is never guaranteed, its intellectual importance is inherent in the requirement that the advance be a nonobvious innovation over prior technology designs to qualify for a patent.[30]

25.

> Patents have long been recognized as a very rich data source for the study of innovation and technical change. Indeed, there are numerous advantages to the use of patent data: each patent contains highly detailed information on the innovation; patents display extremely wide coverage in terms of technologies, assignees, and geography; there are already millions of them (the flow being of over 150,000 US Patent and Trademark Office (USPTO) patent grants per year [as of 2005]); the data contained in patents are supplied entirely on a voluntarily basis . . . .

Bronwyn H. Hall, Adam Jaffe & Manuel Trajtenberg, *Market Value and Patent Citations*, 36 RAND J. ECON. 16, 17 (2005), http://escholarship.org/uc/item/0cs6v2w7.

26. Patented advances, as described in the patent claims portions of patent records, are important milestones in technological development not because they are necessarily functional or commercial triumphs over prior technology, but because, under patent law standards, they must incorporate intellectual milestones in the form of something distinctly new that would not have been obvious to a person of ordinary skill in the technical field of the advance. *See* 35 U.S.C. § 103 (2012); Graham v. John Deere Co., 383 U.S. 1, 14 (1966).

27. *See* §§ 102, 103; *Graham*, 383 U.S. at 14.

28. *See* §§ 102, 103; *Graham*, 383 U.S. at 14.

29. While reviews of patent applications by patent examiners exert pressures on patent applicants to meet patent law standards at the risk of having their applications rejected and receiving no patents, patent examiners are certainly not perfect in their evalautions of patent applications and some unqualified applications do result in issued patents. Patents erroneously issued by patent examiners are subject to futher challenges in post-issuance administrative processes and in court challenges, thereby limiting the impacts of errors in examiners' reviews. Many patents are also communically unimportant and never enforced, thereby further limiting the practical impacts of examiners' errors. *See generally* Mark A. Lemley, *Rational Ignorance at the Patent Office*, 95 NW. U. L. REV. 1495, 1508-11 (2001).

30. *See* 35 U.S.C. §§ 102, 103; *Graham*, 383 U.S. at 14.

Technology outliers constituting nonobvious departures from prior designs are especially important because they generally diverge from normal paths of technology evolution. Such evolution typically occurs through obvious extensions of prior knowledge and designs to produce new, but usually predictable, further designs.[31] Patentable technology designs based on nonobvious new approaches are different. Such outliers have the potential to launch fundamental changes in technical fields by informing new design approaches or types of products.[32] These outlier advances can also point to new directions for subsequent technical development and evolution, thereby redirecting research and engineering projects and fields.[33]

Because of their intellectual importance in defining distinctively new design approaches, patented advances and features of their production (both as described in patent records) constitute significant aspects of technology development. By comparing patented technology development for specific regions, it is possible to identify settings where the production of intellectually significant technology outliers constituting patented advances is particularly vibrant.

B. Patent Records as Sources of Innovation Heritage and Rating Information

Beyond just describing outlier innovations, patents also contain information on the intellectual heritage of those innovations.[34] The heritage of recently patented advances is recorded in citations of earlier patents in later ones.[35] Heritage information of this sort helps to interpret

31. Most innovation involves obvious, predictably functional modifications to prior technology designs because technological innovation occurs by imagining functional solutions to practical problems and our imagination tends to extend what we already know as designs for useful items and processes. *See* Richard Gruner, *Imagination, Invention, and Patent Incentives: The Psychology of Patent Law*, 2018 U. ILL. J.L., TECH. & POL'Y (forthcoming 2018).

32. Of course, not all patented advances have these transformative impacts. Some are simply functionally inferior to other pre-existing design approaches or are impossible to translate into viable products.

33. By encouraging disclosures of technology design approaches that are not obvious to persons of ordinary skill in the relevant field of technology, patents add these approaches to the body of design knowledge available to subsequent innovators (so long as they do not copy the particular elements of a patented design while a patent is still enforcible). The inclusion and disclosure of at least one nonobvious design feature is a requirement of every patented advance. *See* 35 U.S.C. §§ 102, 103; *Graham*, 383 U.S. at 14.

34. *See supra* text accompanying note 8.

35. Citations in recent patents to earlier patents are sometimes referred to as "backward citations" or "forward citations" depending on the perspective of the discussion. The citations are the same under both labels. The labeling depends on whether the citing or cited patents provide the frames of reference. For example, if recent patent B cites earlier patent A, the citation involved is a forward citation with respect to earlier patent A (because the citation occurred

two features of innovation. First, it indicates the intellectual roots and background of patented advances in the earlier advances being cited.[36] Second, and perhaps more importantly, it allows us to identify lines of technological advance that are particularly active and intense.[37] Such lines of advance are identified in relation to past patented advances, with the intensity of the advances gauged from the number of recent patents that cite a given earlier patent. Large numbers of recent citations suggest that the cited advances are related to intensive areas of technology innovation; by rating earlier advances in terms of citation counts, we can assess the relative intensity of innovation related to various patented advances.

1. Reliability of Innovation Heritage Information in Patents

Patent law requirements and related commercial incentives press innovators to provide accurate and complete invention heritage information in patent applications and resulting patents.[38] To qualify for a patent, an advance must both be novel (i.e., have some new feature not present in earlier, publicly revealed designs)[39] and nonobvious (i.e., incorporating at least one feature differing from prior designs that would not have been obvious to well-informed persons with average analytic skills in the technical field of the advance).[40] Inventors seeking patents are required to provide information to the USPTO situating their advances within surrounding technology fields.[41] Disclosure of this

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forward in time from the publication of the patent being cited) and a backward citation with respect to recent patent B (because the citation points to a patent issued backward in time from the citing patent).

36. Patent citations reflect information on the technology background and context of a more recent advance described in a patent application, as accumulated by both the patent applicant and the examiner who reviews that application. *See infra* text at Section II.B.1.

37. The number of later innovators who have cited a particular patent indicates the intensity of new technology development revolving around the technology area of the cited patent. *See infra* text at Section II.B.2.

38. The substantive requirements that must be met in order for an advance to qualify for a patent ensure that only exceptional, nonobvious advances are recorded in patents. *See* 35 U.S.C §§ 101, 103; *Graham*, 383 U.S. at 14. The requirements for minimum information disclosures in patent applications ensure that inventors disclose aspects of the background and intellectual heritage of their advances, providing information that is then recorded in resulting patents. *See* 37 C.F.R. § 1.56 (2016).

39. *See* 35 U.S.C § 101.

40. *See* 35 U.S.C § 103; *Graham*, 383 U.S. at 14.

41. Any party filing a patent application (including an inventor and his or her patent attorney or agent) has a duty of candor and good faith in dealing with the United States Patent and Trademark Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability issues such as the novelty and nonobviousness of an invention relative to prior art in the same field. *See* 37 C.F.R. § 1.56.

information—to the extent that the inventors have it, as no new research is required[42]—helps USPTO patent examiners to understand the range of prior designs (the "prior art") against which the novelty and nonobviousness of an invention must be determined.[43] The failure of a patent applicant to make adequate disclosures can invalidate any patent the applicant receives,[44] potentially resulting in multi-million dollar losses due to invalidation of a highly valuable patent.[45] Hence, there are strong incentives for patent applicants to be accurate and complete in their citations of relevant earlier advances.

2. Using Heritage Information To Rate Invention Intensity

Over time and with the submission of numerous patent applications, accumulated patent records capture multiple assessments by recent innovators of innovation relevance and importance. The result is highly valuable data describing innovation relationships. Accumulated

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Disclosures of relevant prior art known to patent applicants is typically made by citations to prior technology descriptions (including prior patents) in patent applications. The importance of patent citations in describing the intellectual heritage of a patented advance was described by one group of commentators as follows:

> Thus, if patent *B* cites patent *A*, it implies that patent *A* represents a piece of previously existing knowledge upon which patent *B* builds, and over which *B* cannot have a claim. The applicant has a legal duty to disclose any knowledge of the prior art (and thus the inventor's attorney typically plays an important role in deciding which patents to cite), but the decision regarding which citations to including ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence able to identify relevant prior art that the applicant misses or conceals.

Hall, Jaffe & Trajtenberg, *supra* note 25, at 18.

42. *See* 37 C.F.R. § 1.56.

43. Patent examiners add further citations based on their research into related technologies in the course of examining patent application. Patent examiners frequently conduct substantial research into background technologies in reviewing patent applications and often rely on the examiners' additional research results (that is, results beyond information provided by patent applicants) in making decisions about the legitimacy of patent applications. *See* Christopher A. Cotropia, Mark A. Lemley & Bhaven Sampat, *Do Applicant Patent Citations Matter?*, 42 RES. POL'Y 844, 844-54 (2013).

44. *See, e.g.,* Am. Calcar, Inc. v. Am. Honda Motor Co., 768 F.3d 1185, 1188-91 (Fed. Cir. 2014).

45. *See, e.g.,* Matthew M. Peters, *The Equitable Inequitable: Adding Proportionality and Predictability to Inequitable Conduct in the Patent Reform Act of 2008*, 19 DEPAUL J. ART TECH. & INTELL. PROP. L. 77, 89-90 (2008) (describing patent acquired from a small biotechnology company by pharmaceuticals industry giant Hoffmann-La Roche for $330 million and then later invalidated due to intentionally deceptive disclosures by the patent applicants). The draconian consequences for patent applicants and patent attorneys of intentionally withholding prior art information known to be material to a patent examiner's review of a patent application are so severe that one observer has concluded that most applicants and their patent attorneys will be strongly encouraged to make complete disclosures. *See* Christopher A. Cotropia, *Modernizing Patent Law's Inequitable Conduct Doctrine,* 24 BERKELEY TECH. L.J. 723, 763-66 (2009).

information on citations received by particular advances provides especially valuable information on invention intensity and technological focus. By tracking inventors' citations of prior patents, it is possible to measure the intensity of interest of present innovators in past advances.[46]

The citations of interest are often called "forward citations" as they occur forward in time (that is, after the publication of the cited patents).[47] Total forward citations for a patented advance provide a rough rating of the influence of that advance on the work of later inventors.[48] Advances with extensive influence will tend to have large numbers of later citations; advances that are "dead ends" with little influence will have few, if any, later citations. Thus, numbers of forward citations are indicators of the relative influence of advances on later innovation.[49] Analysts have found forward citation counts correlated to estimates of the value of particular patents or patented advances.[50]

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46. It is impossible to determine from a mere patent citation whether a current inventor actually consulted the patent cited for information leading to a current advance. The citation only indicates that the patent applicant making the citation recognizes, in retrospect, that the earlier cited advance is relevant to a current advance for which a patent is being sought. However, the advances being cited were, as required by patent standards, publicly unknown, state of the art advances when made. Once disclosed in patent applications or by other means, the cited advances would frequently have come to the attention of many parties in the relevant field via the rich information transfer capabilities of the Internet and other methods of technology information transfer. Whether or not a current inventor was directly influenced by a patent description of an advance is not the point; whether such an inventor was influenced, via some information transfer method, by the invention described in a cited patent is what is important. Given the originality of cited advances when their relevant patents were issued and the many means by which information on those advances may have come to current innovators in the same field, it seems likely that most current innovators would have substantial means to know of the earlier patented advances in their field well before the made current advances and cited the earlier advances in seeking patents on their current advances.

47. *See, e.g., Using the Citation Analysis*, PAT. INSPIRATION, http://support.patentinspiration.com/hc/en-gb/articles/207202703-Using-the-Citation-analysis (last visited Oct. 14, 2017) ("forward citations [result from] patents that cite a specific patent"). Backward citations, in contrast, result from patents that are cited by a specific patent. *See id.*

48. Influence as used here refers to the conceptual relevance of a later invention to an earlier one (as perceived by the innovator making the later one). An advance with numerous relevant successors is deemed to have great influence regardless of whether the parties producing the successor advances considered and consciously built upon or improved the prior advance. The prior advance is treated as having high influence because it has placed design concepts into the relevant technical art that are replicated and built upon in many later advances.

49. *See* Bronwyn H. Hall, Adam B. Jaffe & Manuel Trajtenberg, *The NBER Patent Citations Data File: Lessons, Insights and Methodological Tools* 21 (Discussion Paper No. 3094, Dec. 2001), http://www.researchgate.net/profile/Adam_Jaffe/publication/5075529_The_NBER_Patent_Citations_Data_File_Lessons_Insights_and_Methodological_Tools/links/543fa9140cf2be1758cea3f0/The-NBER-Patent-Citations-Data-File-Lessons-Insights-and-Methodological-Tools.pdf (using forward citations as indicators of the impacts of patents).

50. *See, e.g.,* Dietmar Harhoff, Francis Narin, F. M. Scherer, & Katrin Vopel, *Citation Frequency and the Value of Patented Inventions*, 81 REV. ECON. & STAT. 511, 511 (1999).

3. The Special Value of Quick Citations

Forward citation counts can be measured at any time during or after the expiration of patents. Many studies have looked to forward citations over the full life of applicable patents.[51] However, there is a significant practical objection to using patent citations over the full life of relevant patents as indicators of patented advance influence. This approach provides influence information and ratings only after the passage of such long periods as to render the associated information largely useless. A forward citation analysis that ends with patent expiration characterizes the importance of an advance made at least twenty years before (since patent expiration under U.S. law will typically occur twenty years after the patent application on the advance was filed).[52] This approach provides information on very old technologies, information that may not be of much use. It would be much more helpful to have meaningful invention rating and influence information based on partial forward citation counts made earlier in the life of the related patents.

Fortunately, recent research suggests that early-stage forward citations—made no later than three years into the life of cited patents—can be highly predictive of technology value growth.[53] Forward citations during the first three years from patent publication (referred to here as "quick forward citations" or "quick citations") were better predictors of value growth rates[54] than forward citation counts assessed over the full

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51. *See, e.g.*, *id.* at 511; Hall, Jaffe & Trajtenberg, *supra* note 25, at 17; Manuel Trajtenberg, *A Penny for Your Quotes: Patent Citations and the Value of Innovations*, 21 RAND J. ECON. 172, 175 (1990).

52. For patents with a filing date of June 8, 1995, or later, the term of patent protection will typically last twenty years from the date the application for the patent was filed or, if the patent application contains a specific reference to an earlier filed application, to the date of that earlier application. *See* 35 U.S.C. § 154(a)(2) (2012).

53. Studies have shown that fields with high averages of forward citations per patent in the first three years after patent publication generally have high rates of growth in product productivity per unit cost and value. *See* Christopher L. Benson & Christopher L. Magee, *Quantitative Determination of Technological Improvement from Patent Data*, PLoS ONE, Apr. 15, 2015, at 11, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0121635&type=printable. Patented innovations with relatively large numbers of forward citations point to fields that are interesting to large numbers of later innovators. Advances with few forward citations, by contrast, appear to reflect technological dead ends in which few additional innovators have followed up with related innovations. *See id.*

54. "Value growth rates" refer here to the technology "improvement rates" studied by MIT researchers Christopher L. Benson and Christopher L. Magee. *See id.* Benson and Magee's research focused on changes in technology functionality delivered per unit cost of technologies—that is, on changes in the value of technologies over time. For example, the relevant functionality performance metric used for solar energy technologies was a watts of electricity generated/dollar cost of solar power equipment. Bensen and Magee found that they were able to make good predictions of technology-specific improvement rates for diverse technologies using only

life of cited patents.[55] Quick forward citations identify advances with intense and rapid interest among current inventors, thereby producing "crowdsourced" information on invention significance.[56] Recent inventors are the "crowd" supplying information in this process, signaling their recognition of past advances as relevant precursors to present innovations through citations to patents covering the past advances.[57]

Using quick forward citations, it is possible to characterize the projected value growth for advances made only about five years earlier.[58] One study was able to use mean quick citation values for fields of technology (in conjunction with mean patent publication dates) to predict approximately 64% of the variation in value growth rates across diverse technology fields.[59] This approach promises to provide useful information both for the targeting of additional research in still fresh fields and for characterizing the potential value of products and services that are based on new technologies.

4. Unpacking the Meaning of Quick Citations

We still do not fully understand why high mean values for quick citations in entire fields of technology frequently correspond to high value growth rates. Innovators may cite prior patents for a number of reasons, each suggesting a somewhat different logic for why high mean citation levels relate to high value growth. Each of these reasons suggests that patents with high quick citation counts are important, but why they are important varies. This Section explores the possible reasons for linkages between high quick citation levels and technology value growth with the aim of explaining what quick citation counts may really be indicating.

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information on patent forward citations in the first three years after patent publication and further information on the date of publication of the related patents. *See id.* The methodology used in Benson and Magee's analyses is explained more fully in note 97. *See infra* note 97 and accompanying text.

55. *See* Benson & Magee, *supra* note 54, at 12.

56. *See Crowdsourcing*, *supra* note 10.

57. The citations of interest are often called "forward citations" as they occur forward in time (that is, after the publication of the patents being cited). *See Using the Citation Analysis*, *supra* note 47.

58. This will be the case if the advances under study were addressed in patent applications submitted soon after the advances were made, the applications were pending for one to three years in the USPTO, and the forward citations for the advances were determined three years after the publication of the related patents.

59. *See* Benson & Magee, *supra* note 54, at 19.

a. Indicators of Innovators' Perception of Invention Value

A current innovator may cite a prior patented advance because the innovator perceives value in the cited advance and has created a newer advance incorporating and building upon the value of the cited advance. This will be the case where an innovator has supplemented the cited advance with added features in a current invention or has altered the cited advance to produce a current invention.[60] In either type of innovation derived from a cited advance, a citation reflects the perceived value of the cited advance. The citation is an indication that the current innovator has recognized the practical value of the earlier advance and has carried that value forward in aspects of a current design.

Under this interpretation, forward citations reflect perceptions of invention value by current innovators. The innovators have recognized the value of cited advances and have built that value into their later advances.[61] If this is the source of most forward citations, it is not surprising that high mean citation levels for particular technical fields frequently correspond to high value growth for those fields. Patents are cited because of their perceived value; fields with high mean citation levels are ones with many patents perceived as having high values by innovators.

Quick citation levels in the first three years after patent publication—as opposed to forward citation levels spanning longer periods—reflect particularly quick and intensive interest in the advances cited.[62] High mean quick citation levels point to fast moving fields in which the value of underlying cited advances is assessed rapidly and translated quickly into further advances and products at an intense pace. Quick citations provide information on "invention immediacy"—the rate of technology change, as indicated by the degree to which innovators rely on and react to very recent discoveries.[63] Innovation fields with high innovation immediacy are intellectually vibrant with very rich "research fronts" producing rapid incorporation of new knowledge in additional advances.[64] Where innovation significance and innovation immediacy are both present, large quick citation counts signal intense development

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60. "[I]f patent *B* cites patent *A*, it implies that patent *A* represents a piece of previously existing knowledge upon which patent *B* builds . . . ." Hall, Jaffe & Trajtenberg, *supra* note 25, at 18.

61. *See id.*

62. Benson & Magee, *supra* note 54, at 11 ("[T]here is a *strong relationship* between the average citations in the first three years to the patents in a technological domain and the associated [technology improvement rate].").

63. *Id.*

64. *Id.*

of related technologies and the potential high value of corresponding technology fields.

b. Indicators of Important Technology Development Targets

A current innovator may also cite an earlier patent to better describe the common problem addressed by both the cited advance and the innovator's current design. This type of citation might be made to help the current innovator distinguish his or her advance from prior attempts to solve an important practical problem. Under this interpretation, high quick citation counts clustered around particular advances may indicate that the cited advances address important problems shared by many parties (even if the cited advances do not necessarily solve those problems or do not solve them very well). High quick citation counts point to commercially interesting problems with large numbers of potential consumers and strong continuing efforts to resolve the problems. Where the problems associated with the high counts are resolved (not necessarily via the cited advances), the presence of large numbers of consumers with a new practical solution makes it likely that large commercial value growth will result. From this perspective, high numbers of forward citations point to important problems and intense solution efforts but do not necessarily indicate the practical success of the patented advances being cited.

c. Indicators of Commercial Support for Research Activity

A large number of current innovators may also cite a prior patent because there is a burst of current research activity in the technology area of the prior patent, perhaps due to a correspondingly high level of commercial backing for research in a particular field. The availability of a burst of funding support for a particular type of research may result in large numbers of inventions and patent citations flowing from this research. Hence, the driving forces behind large quick citation counts for particular advances may be corresponding changes in funding and resource allocations that trigger enhanced research levels. High quick citation counts under this view are indicators of high commercial interest in specific research fields and commercially significant practical problems.[65] High counts relate to value growth to the extent that research

65. *See, e.g.*, Hall, Jaffe & Trajtenberg, *supra* note 25, at 24 ("There are reasons to believe that citations convey not just technological but also economically significant information: Patented innovations are for the most part the result of costly R&D conducted by profitseeking organizations; if firms invest in further developing an innovation disclosed in a previous patent,

backers spend their money wisely. If resource providers accurately project types of research that tend to have important commercial value when successful, highly supported research leading to high quick citation counts should also correlate with high value growth.

d. Quick Citation Implications in the Present Study

All of the potential implications of quick citations described above suggest that advances with high quick citation counts are interesting and important indicators of positive features of technology development (for somewhat different reasons, depending on which of the interpretations is correct). It is not possible based on present understanding to know which of these interpretations is correct or whether a blend of these or other reasons account for high citation levels in technology fields with high value growth. However, it is not necessary to resolve this point for purposes of the current study. High quick citation counts point to important patented advances, either because the advances have value themselves or because they target interesting and commercially important practical problems as perceived by innovators or research funders or both. For the purposes of this Article, patents with high quick citation counts will be referred to as having substantial influence on later advances, but it should be understood that these patents may be important for the other reasons discussed in this Section. The study describes the innovation settings and processes producing these interesting patents. These findings are significant regardless of the reasons why the underlying patents are interesting.

C. Uses of Quick Citations in the Present Study

Patent citation information is used in several ways in the present study. High patent citation counts—particularly counts of citations to patents during the first three years after patent publication—frequently track technology fields that are experiencing large value growth.[66] This suggests that recent patent records and associated citations can point to fields with high potential for future value growth.[67] This Article uses national patent data to identify technology fields with high citation counts and correspondingly high likelihoods of substantial value growth

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then the resulting (citing) patents presumably signify that the cited innovation is economically valuable.").

66. Average citation counts across several different technologies were found to be correlated with growth rates for functional outputs per unit cost in the same technologies. *See* Benson & Magee, *supra* note 54.

67. *See id.*

then goes on to show that San Francisco innovators produce especially large numbers of advances in high growth fields.

Patent citations are also used here to identify advances that have received especially large attention from recent innovators. These high interest advances are "outliers among outliers." First, as patented inventions, they are intellectual outliers in the sense that all patented advances are nonobvious outliers departing in somewhat unpredictable ways from prior technology designs.[68] Second, high interest advances are outliers among patented advances in the exceptionally great attention they have received from later innovators, reflecting in their high citation counts greater than normal relevance to later advances and correspondingly large technological influence.[69] Such high attention advances are standouts in their fields, at least when measured in recognition by subsequent inventors. These standouts appear in patent records across diverse technology fields, regardless of whether the fields are ones generally having high or low citation counts and projected values.[70] As this study will show, San Francisco innovators produce significantly higher fractions of these high interest advances than innovators elsewhere.

This Article describes several other distinctive features of San Francisco innovation using evidence from patent records, including the importance of especially large innovation teams,[71] the enormous influence of patented advances from this region on subsequent innovation,[72] and local variations in innovations by residents of cities within the San Francisco Region.[73]

III. PREVIOUS EVALUATIONS OF SAN FRANCISCO INNOVATION USING PATENT RECORDS

This Article builds on earlier examinations of San Francisco innovation using patent records.[74] The prior studies have emphasized the

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68. *See* 35 U.S.C. § 103 (2012); Graham v. John Deere Co., 383 U.S. 1, 14 (1966).

69. As discussed in Section IV.G, a remarkable fraction of patented advances appear to be ignored by subsequent innovators. *See infra* Section IV.G.

70. The presence of exceptionally high quick citation counts in technology fields with both high and low mean citation levels is described in Section IV.E, *infra*.

71. *See infra* Section IV.A.

72. *See infra* Section IV.B.

73. *See infra* Part V.

74. *See, e.g.,* Chris Forman, Avi Goldfarb & Shane Greenstein, *Agglomeration of Invention in the Bay Area: Not Just ICT*, 106 AM. ECON. REV., no. 5, May 2016, at 146; Florida, *supra* note 1; Annalee Newitz, *A Bizarre Statistical Fact About Patents in San Francisco*, GIZMODO (Feb. 4, 2015), http://gizmodo.com/a-bizarre-statistical-fact-about-patents-and-theft-in-s-1682643480.

quantities of patented innovations produced in San Francisco and the substantial growth in these quantities in recent years.[75] The present study expands on these earlier efforts by examining the quality and influence of patented advances produced in San Francisco.

This Part summarizes findings of other investigators who have employed patent records as lenses for studying San Francisco innovation. These studies confirm that, since the early 1990s, San Francisco has experienced (and continues to enjoy) great success in the production of patented innovations.[76]

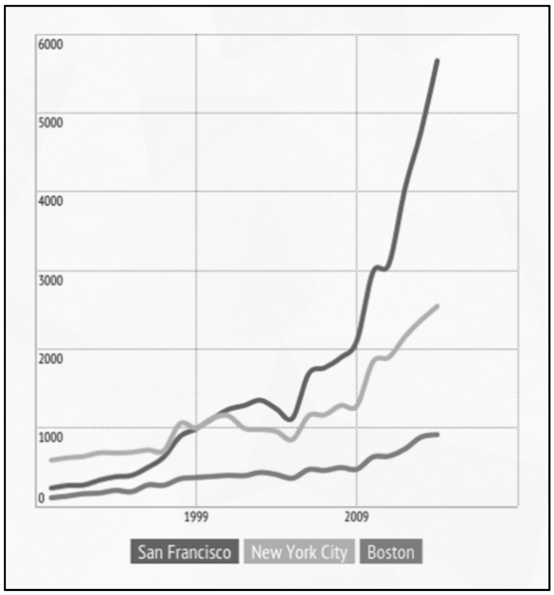
A. Quantities of Innovation

Many researchers have conducted studies to quantify San Francisco's innovation prominence over that of other cities. Richard Florida found evidence in patent records of large increases in quantities of patented advances reflecting San Francisco's increasing dominance over U.S. innovation.[77] San Francisco innovation (as measured from issued patents) increased by about two orders of magnitude between 1990 and 2015.[78]

San Francisco's innovation growth was not a mere local reflection of national trends. Innovation rose in San Francisco at rates far above the growth rates for other major innovation centers. The following figure (prepared by Annalee Newitz) compares the growth between 1990 and 2015 in patented inventions originating in San Francisco, New York City, and Boston, illustrating how substantially San Francisco outdistanced these other technology sources[79]:

75. *See* Forman, Goldfarb & Greenstein, *supra* note 74; Florida, *supra* note 1.
76. *See* Forman, Goldfarb & Greenstein, *supra* note 74; Newitz, *supra* note 74.
77. *See* Florida, *supra* note 1.
78. *See* Newitz, *supra* note 74.
79. *Id.*

Figure 1:
Growth in Patents 1990-2015: San Francisco, New York, and Boston

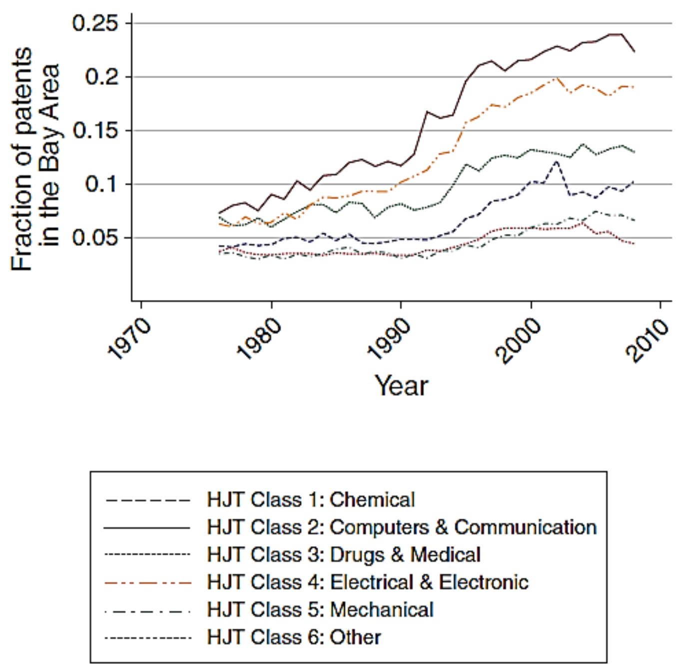


Researchers Chris Forman, Avi Goldfarb, and Shane Greenstein, again relying on patent records, not only confirmed San Francisco's significant innovation growth in recent years but also found that this growth extended across diverse technologies.[80] Their study indicated that San Francisco innovation expanded in technologies ranging from computer designs to pharmaceutical drugs despite the vast differences in these technologies and how they are developed.[81] Examining patents issued to innovators from San Francisco (including teams with at least one San Francisco inventor), Forman, Goldfarb, and Greenstein found an enormous jump in patenting by San Francisco inventors between 1976 and 2008, including significant growth in multiple technology fields.[82] They concluded that this growth reflected "coagglomeration" of innovation across many high-tech industries in the Bay Area.[83] The

80. Forman, Goldfarb & Greenstein, *supra* note 74.
81. *Id.* at 149.
82. *Id.* at 146.
83. *See id.* The coagglomeration of innovation across multiple technologies—essentially the joining in a particular geographic area of high levels of technology development across diverse technologies—may occur for a number of reasons. The reasons involve technology development advantages aiding diverse types of technology innovation. Forman, Goldfarb, and Greenstein reach no firm conclusions regarding the reasons for the coagglomeration they perceive in the San Francisco Bay Area but suggest that the broadly focused technology success

following figure (prepared by Forman, Goldfarb, and Greenstein) breaks down the changes in San Francisco innovation by technology category (the references here to HJT technology classes refer to technology groupings developed by Bronwyn H. Hall, Adam B. Jaffe, and Manuel Trajtenberg)[84]:

Figure 2:
San Francisco Innovation by Technology Category—1976 to 2008



The growth in patenting by San Francisco innovators is particularly striking because it came in a period of relatively flat patenting levels in many other major American cities.[85] The following figure (also created by Forman, Goldfarb, and Greenstein) summarizes the fractions of total

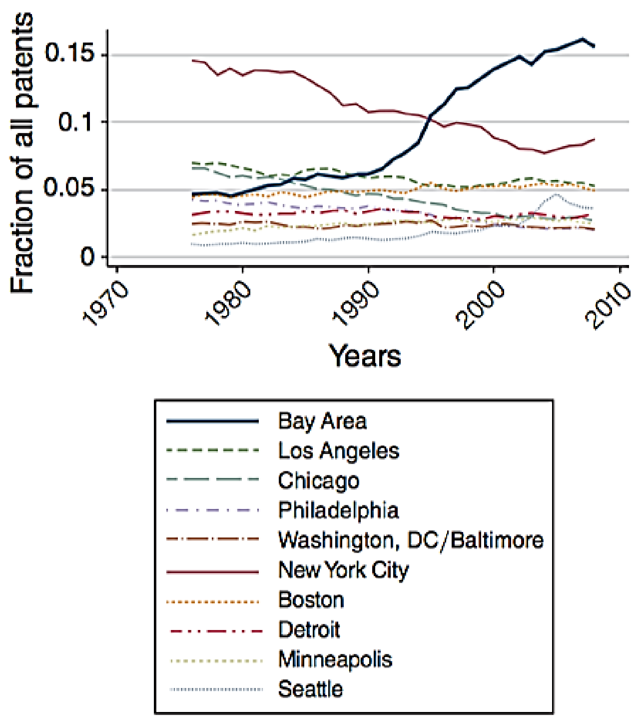
seen in this region may have resulted from such factors as the nonenforcement of non-compete clauses, local expertise in startup financing, shared labor markets across invention types, or knowledge spillovers across invention types. *See id.*

84. *Id.* at 149; *see also* Hall, Jaffe & Trajtenberg, *supra* note 49 (alternatively grouping technologies into six main categories: "Chemical (excluding Drugs); Computers and Communications (C&C); Drugs and Medical (D&M); Electrical and Electronics (E&E); Mechanical; and Others").

85. *See* Forman, Goldfarb & Greenstein, *supra* note 74, at 148.

U.S. utility patents produced in the ten cities that were the top sources of patents in 1976 to 2008[86]:

Figure 3:
Patenting in Top Ten American Cities—1976 to 2008



Two features of this figure stand out. First, the fractions for the San Francisco Bay Area and New York City dwarf those for the other top ten cities indicated. Second, although it is of a similar magnitude to San Francisco's fraction, the fraction for New York City shows a clear downward trend over the years 1976 to 2008 while San Francisco's shows a striking upward movement.

The significant growth in San Francisco innovation reflected in these figures was supported by parallel growth in venture capital

86. *Id.* This graph differs from the graph of patent counts produced by Annalee Newitz in that it focuses on the fractions of all U.S. patents emerging from the indicated cities rather than the total number of patents as used by Newitz. *See* Newitz, *supra* note 74. The focus on fractions of the total number of patents is arguably preferable as it allows year to year comparisons without the confounding effects of the national growth in overall numbers of issued patents from year to year.

investment.[87] Between 1995 and 2016, the Bay Area's share of venture capital investment increased from 22.6% of the national total to 46.5%, with a 6% increase in the five years from 2010 to 2015 alone.[88] The Bay Area now receives about 40% of all venture capital investment in high-tech startups in the United States and more than 25% of such investment worldwide.[89] Whether venture capital investment growth has spurred new technology growth in the Bay Area or just followed that technology growth is unclear; what is clear is that decision makers in venture capital firms see San Francisco's high-tech startups as distinctly promising and important targets of enormous investment support.

IV. MORE PATENT INSIGHTS INTO SAN FRANCISCO'S INNOVATION BOOM: THE PRESENT STUDY

The present study of innovation in the San Francisco Region (including advances from Silicon Valley and as far south as San Jose) illustrates the usefulness of quick citation counts in analyzing regional innovation features. Interpreting innovation features based on information from patent records, it is possible to better understand why San Francisco-based innovation has been so commercially and technologically influential. Two indicators of the success of San Francisco innovation stand out in patent records: (1) innovation in this region has produced numerous patented advances in technology fields predicted to have high value growth, and (2) within these high value fields, San Francisco innovation has produced numerous advances with exceptionally high numbers of quick citations and correspondingly high likely influence on later advances. In short, San Francisco innovation is characterized by especially influential outliers in generally valuable technical fields.

The study data are drawn from a large sample of patented inventions and quick citations regarding the same inventions.[90] The

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87. Florida, *supra* note 1.
88. *Id.*
89. *Id.*
90. The sources for the data used in this study were as follows:

(1) Data on inventors, technology classes, inventor numbers per patent, and forward citations in the first three years after patent publication were obtained from the AcclaimIP database. *See* ACCLAIM IP, http://www.acclaimip.com/ (last visited Oct. 23, 2017). The data used covered all U.S. utility patents published in June 2012. Forward citations to these patents during the first three years after patent publication were obtained by performing a search for then-current forward citation totals three years after June 2012.

(2) Additional information on inventor locations was obtained by downloading data from PatentsView and linking this to the patent information already obtained. *See* U.S. Patent &

sample includes inventions described in 18,448 U.S. utility patents published during June 2012, which document the work of 49,976 inventors. Of these patents, 1763 described San Francisco innovations, reflecting contributions by a total of 3985 San Francisco inventors. For purposes of this study, an advance was treated as a San Francisco innovation if at least one inventor of the advance lived in the San Francisco Region, including areas north of the city, the east bay (including Berkeley, Oakland, and nearby cities) and south through Silicon Valley to cities as far south as Los Gatos.[91]

The sample data describing San Francisco innovations and innovations emerging elsewhere reflect a wide variety of technologies and are believed to be representative of contemporaneous patents and innovations generally. The following breakdown of numbers and percentages of patents in the ten technology classes with the largest numbers of U.S. utility patents published in 2012 indicates that the technology mix in the sample set from June 2012 generally tracked that in the full set of 276,796 patents issued in 2012[92]:

Trademark Office, *Data Download Tables*, PATENTSVIEW, http://www.patentsview.org/download/ (last visited Oct. 23, 2017).

(3) Data on assignments of the patents was obtained from the USPTO's Patent Assignment Dataset, with data extracted for the relevant patents and linked to the previously obtained data for each patent. *See Patent Assignment Dataset*, USPTO, http://www.uspto.gov/learning-and-resources/electronic-data-products/patent-assignment-dataset (last visited Oct. 23, 2017).

91. The specific map coordinates used to define the San Francisco Region were latitude>37.209679 & latitude<38.217810 & longitude>-123.072063 & longitude<-121.542217. Advances with at least one inventor resident within the rectangle defined by these coordinates were considered "San Francisco innovations." The aim in most portions of the study was to examine all innovation projects in which at least one contributor was from the San Francisco area.

Portions of the study used additional geographic criteria, which are identified in the relevant discussions. For example, one portion of the study attributed each advance to a single primary geographic origin (by allocating each advance to the location of its lead inventor). *See infra* Section V.A.1. The aim of this portion was to assess the regional features of advances not inventors. Further portions of the study characterized innovation features (including technology specializations) by attributing advances to specific communities within the San Francisco Region. See *infra* Part V. Here, the aim was to look for communities that reflected distinctive technology specialization among innovators producing patented advances.

92. Nationwide counts for patents in the indicated technology classes were obtained from the USPTO. *See Patent Counts by Class by Year: January 1977—December 2015*, USPTO, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cbcby.htm (last visited Oct. 23, 2017).

Table 1:
Technology Breakdowns

Class	Class Title	2012 Number	2012 Percent	Sample Number	Sample Percent
370	Multiplex Communications	8401	3.04%	632	3.42%
455	Telecommunications	7616	2.75%	589	3.19%
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	6884	2.49%	441	2.39%
514	Drug, Bio-Affecting and Body Treating Compositions	5367	1.94%	418	2.26%
709	Electrical Computers and Digital Processing Systems: Multicomputer Data Transferring	5313	1.92%	367	1.99%
438	Semiconductor Device Manufacturing: Process	5176	1.87%	347	1.88%
382	Image Analysis	5145	1.86%	341	1.84%
707	Data Processing: Database and File Management or Data Structures	4969	1.80%	393	2.13%
705	Data Processing: Financial, Business Practice, Management, or Cost/Price Determination	4863	1.76%	345	1.87%
345	Computer Graphics Processing and Selective Visual Display Systems	4854	1.75%	379	2.05%
ALL	ALL CLASSES	276,796	100.00%	18,484	100.00%

The patents in this sample, along with related information on quick citations (up through June 2015), inventor locations, and patent assignments, were used to characterize San Francisco innovation and to compare it to innovation elsewhere. A citation was considered a quick citation if the forward citation occurred within three years of June 2012—that is, if the citation occurred before June 30, 2015. These comparisons revealed several significant differences between innovation in the San Francisco Region and elsewhere. This Part describes the findings from these comparisons.

A. *San Francisco Innovation Is Highly Collaborative*

Heavy reliance on collaborative innovation is one distinctive feature of San Francisco innovation apparent from patent records. San Francisco innovators rarely acted alone in producing patented advances published in June 2012. Rather, they worked in collaborative teams much more frequently than innovators elsewhere. Innovation teams, some of remarkably large size, produced the bulk of San Francisco advances published in June 2012.

The team dynamics underlying San Francisco innovation are apparent from the breakdown in Table 2 of inventor team sizes for advances from this region. The San Francisco inventions examined in this study were covered by 1763 patents with an average inventor team size of 3.16. The distribution of team sizes was as follows:

Table 2:
Team Sizes for SF Innovations

Inventor Count	Frequency	Percent	Cumulative Percent
1	399	22.63%	22.63%
2	441	25.01%	47.65%
3	352	19.97%	67.61%
4	203	11.51%	79.13%
5	148	8.39%	87.52%
6	90	5.1%	92.63%
7	50	2.84%	95.46%
8	37	2.1%	97.56%
9	13	0.74%	98.3%
10	7	0.4%	98.7%
11	7	0.4%	99.09%
12	4	0.23%	99.32%
13	4	0.23%	99.55%
14	3	0.17%	99.72%
15	1	0.06%	99.77%
16	1	0.06%	99.83%
17	2	0.11%	99.94%
18	1	0.06%	100.00%
Total	1763	100	

While most patented innovations from San Francisco in this period emerged from teams of three or smaller, there were some very large teams behind some of these innovations. About 5% of the innovations involved teams of eight persons or larger.

Innovations from outside the San Francisco Region tended to involve both more solo inventors and smaller teams. The contrast in both these features is striking. Patented inventions not involving any San Francisco innovators corresponded to a total of 16,721 patents published in June 2012, with an average team size of 2.66. The team size breakdown was as follows:

Table 3:
Team Sizes for Innovations Outside SF

Inventor Count	Frequency	Percent	Cumulative Percent
1	5420	32.41%	32.41%
2	4157	24.86%	57.27%
3	3025	18.09%	75.36%
4	1923	11.50%	86.86%
5	960	5.74%	92.60%
6	536	3.21%	95.81%
7	320	1.91%	97.72%
8	159	0.95%	98.67%
9	76	0.45%	99.13%
10	59	0.35%	99.48%
11	26	0.16%	99.64%
12	19	0.11%	99.75%
13	17	0.10%	99.85%
14	10	0.06%	99.91%
15	6	0.04%	99.95%
16	3	0.02%	99.97%
17	3	0.02%	99.98%
18	0	0.00%	99.98%
19	1	0.01%	99.99%
26	1	0.01%	100.00%
Total	16,721	100%	

Solo inventors accounted for a much higher fraction of the total (32.41% versus 22.63%), while large teams produced a much smaller fraction of the total (2.38% for teams of eight or larger for innovation outside San

Francisco versus 4.64% for teams of eight or larger involving at least one San Francisco inventor).

A number of factors may encourage innovation through team efforts and large teams rather than small ones. Large teams may be advantageous for certain types of complex research (where large teams may help to bring together specialized knowledge or skills, each component held or managed by a different team member). Large teams may also result from pre-existing institutional or organizational structures or processes that have assembled working teams and that cause parties to work together in specific groups over multiple projects.

However, the advantages of large working groups come at the cost of coordination and communication burdens.[93] The disadvantages of working with groups of innovators stem from the incremental communication and coordination tasks that multiple innovators must accomplish in working together on group projects that individuals do not face in working alone.[94] The most desirable group size for a particular innovation project will balance the advantages of more participants with broader backgrounds or other advantageous contributions against the disadvantages of needing to coordinate efforts of additional team members to make effective group progress.

The greater prevalence of large teams in San Francisco innovation than elsewhere may be a response to the demands of the technologies that predominate in this region (in which case, large teams are probably needed to be effective in pursuing those technologies) or may reflect lower team coordination costs due to attitudes or approaches to group work that are distinctive to the Bay Area (in which case, the large teams in this region point to coordination methods or other team-enhancing resources that may assist diverse technology projects and may be highly valuable if replicated elsewhere). Determining which of these (or other) factors explain the highly collaborative features of San Francisco innovation will require further study.

B. Regional Innovation Influence

Looking at San Francisco innovation as a regional whole, there is clear evidence in the patent data considered here that advances from this region have significantly greater influence over subsequent innovation than advances from other sources. This is apparent from the high means

93. Richard S. Gruner, *The Evolution of Collaborative Invention at a Distance: Evidence from the Patent Record*, *in* CREATIVITY, LAW AND ENTREPRENEURSHIP 186, 187 (Shubha Ghosh & Robin Paul Malloy eds., 2011).

94. *Id.*

values for quick citations to advances from the San Francisco Region. Advances from San Francisco were cited in the first three years after patent publication at a rate almost twice that for patented innovations originating elsewhere.

Table 4 summarizes the differences in quick citations for patents published in June 2012. The two entries compare mean quick forward citations for advances involving at least one San Francisco innovator with the same mean citation values for advances originating elsewhere. On a per patent (per invention) basis, this comparison was as follows:

Table 4:
Regional Innovation Influence per Patent

Inventions from San Francisco Region

Patents	Mean Citations	Std. Dev.	Minimum	Maximum
1763	4.230	8.019	0	90

Inventions from Outside the San Francisco Region

Patents	Mean Citations	Std. Dev.	Minimum	Maximum
16,721	2.316	4.955	0	139

Making the same comparison on a per inventor basis—comparing quick citations to the work of San Francisco-based inventors to quick citations for advances by inventors elsewhere—produces a similar difference in mean quick citation levels. For purposes of this analysis, forward citations to a particular advance were allocated evenly among multiple members of teams that produced the advances. Thus, for example, if an advance produced by a five-member team received two quick citations, each team member was allocated 2/5 or .4 quick citations. These quick citations distributed among multiple team members are referred to here as "allocated quick citations." The mean allocated quick citations for San Francisco innovators and those elsewhere were:

Table 5:
Regional Innovation Influence per Inventor

Inventors from San Francisco Region

Inventors	Mean Allocated Citations	Std. Dev.	Minimum	Maximum
3985	1.54	3.64	0	74

Inventors from Outside the San Francisco Region

Inventors	Mean Allocated Citations	Std. Dev.	Minimum	Maximum
45,991	0.87	2.24	0	139

The differences in these tables illustrate the far greater impact of work of San Francisco inventors compared to contemporaneous innovations by researchers elsewhere. The relative impact of advances from San Francisco (as measured from quick citations on a per patent basis) is 4.230/2.316 or approximately 183% of that for advances produced elsewhere.

The difference in influence for innovations from San Francisco and elsewhere was statistically significant. Treating innovations from San Francisco and elsewhere as two samples of overall invention processes in the period under study, the distributions of quick citations for these two samples were compared using the Wilcoxon-Mann-Whitney test.[95] The test produced a Z statistic of -13.791, indicating that there was a statistically significant difference (at the .001 level) between the distributions of quick citations for patented advances from the San Francisco Region and advances produced elsewhere. This confirms that advances involving San Francisco innovators were cited at materially higher levels in the first three years after patent publication than all other contemporary advances. Across the many technologies that make up San Francisco innovation, San Francisco innovators produced advances with quick and large recognition by subsequent innovators at

95. The Wilcoxon-Mann-Whitney test is a non-parametric test for the similarity of two samples of data. *See Ranksum—Equality Tests on Unmatched Data*, STATA 1, http://www.stata.com/manuals14/rranksum.pdf (last visited Oct. 24, 2017). This test is an analog to the independent samples t-test for use when, unlike the t-test, it cannot be assumed that the data under study are normally distributed. The quick citation data under study are right skewed and not normally distributed. Hence, the Wilcoxon-Mann-Whitney test was employed rather than the more common t-test. *See* Jonathan Bartlett, *Wilcoxon-Mann-Whitney as an Alternative to the T-Test*, STATS GEEK (Apr. 12, 2014), http://thestatsgeek.com/2014/04/12/is-the-wilcoxon-mann-whitney-test-a-good-non-parametric-alternative-to-the-t-test/.

levels significantly higher than inventors elsewhere. Specific areas of technology strengths in San Francisco innovation are addressed at a later point in this Article.[96]

C. *Projecting the Overall Value of San Francisco Innovations*

Quick citations to San Francisco innovations offer means to project the value of advances from this region relative to innovations from other sources. Previous research has determined that mean quick citation values for particular technology classes are good predictors of value growth rates for those classes.[97] These mean values (in combination with further data on patent publication dates) successfully predicted approximately 64% of the variations in value growth across diverse technologies.[98]

Using the analytic model developed in this prior research, it is possible to predict the value growth rate for advances emerging from the San Francisco Region and to compare that rate to the projected growth rate for advances originating elsewhere. This use of quick citations to predict value growth rates is a bit different than in the prior research that developed the model. The prior research predicted value growth rates for particular classes of technologies;[99] here the aim is to predict growth rates for regions producing a mix of technologies. However, the relationship of quick citations to value growth rates found in the prior research should hold for the mix of technologies at issue here. This is true because the

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96. *See infra* Section IV.E.

97. *See* Benson & Magee, *supra* note 54. Benson and Magee examined functionality improvements for various types of technologies as measured in terms of functionality provided per unit technology cost. *See id.* at 1. For example, the relevant functionality performance metric used for solar energy technologies was a watts of electricity generated/dollar cost of solar power equipment. *Id.* Using similar performance metrics for a wide variety of technologies, Benson and Magee computed improvement rates for specific technologies. *Id.* at 2-6. They computed exponential growth rates k for specific technologies using the formula q1=q0exp(k(t1 - t0)), where q1 and q0 equaled the performance measures for a given technology at times t1 and t0, and k equaled the technology-specific improvement rate. *Id.* at 1. The exponential technology improvement rates k varied substantially over the different technologies studied. *Id.* at 10-15. High improvement rates reflected faster changes in functionality per cost ratios over time. *Id.* However, since the functionality per cost ratios used were effectively measures of technology value, the technology "improvement rates" studied by Benson and Magee are referred to as "value growth rates" here. *See id.* at 1 (defining the "technological improvement rate" as "the performance improvement over time for a specific generic function that the technological domain is accomplishing"). Bensen and Magee found that they were able to make good predictions of technology-specific growth rates (that is, in k values) across technologies using only information on patent forward citations in the first three years after patent publication and further information on the date of publication of the related patents. *See id.* at 15-19.

98. *Id.* at 19.

99. *See id.* at 6-10.

overall value growth rate for a group of mixed technologies is composed of the sum of the growth rates for the component technologies reflected in the mixed technologies weighted by the prevalence of various technologies in the overall mix. By taking these two factors (technology-specific growth rates and prevalence of technologies) into account, it is possible to predict the value growth for the mix of technologies produced by innovators in the San Francisco area and to compare this growth rate to the similar rate for innovations from other sources.

The mean quick citation value for San Francisco inventions captures the necessary information on these two factors and can therefore support estimates of value growth for advances from the region.[100] Using the model developed in past research by Christopher L. Magee and Christopher L. Benson,[101] quick citations to patents published in June 2012 predict a value growth rate (VGR) described by the following formula[102]:

$$VGR = .0155(MeanYear) + .141(QuickCites) - 31.197$$

Where:

VGR = value growth rate (that is, the annual exponential growth rate of the performance/cost ratio for the patented technologies)[103]

MeanYear = mean publication year for patents considered

QuickCites = mean citations received within three years

Combining this formula with the per patent quick citation means described earlier for patents published in June 2012 produces the

100. This mean quick citation value for the mix of technologies from the region is the sum of the means for the component technologies in the mix, weighted by the prevalence of each component technology. Hence, both types of information (mean quick citation levels that are proportional to value growth figures for the corresponding technology classes and class prevalence information) are captured in the overall quick citation mean value for the region.

101. *See* Benson & Magee, *supra* note 54.

102. *See* Christopher L. Benson & Christopher L. Magee, *Correction: Quantitative Determination of Technological Improvement from Patent Data*, PLoS ONE, Mar. 21, 2016, at 3, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0151931&type=printable (issuing a correction to Table 4 of Benson & Magee, *supra* note 54, at 14).

103. VGRs are used to predict changes in technology performance per unit cost through the following formula:

$$q = q0 \exp\{k(t-t0)\}$$

where:

q = performance at time t (measured in functionality per unit cost; e.g. watts/dollar)

k = value growth rate (VGR)

t = time in years

t0 = Initial time

q0 = q at time t0

Under this approach, after elapsed time t, performance levels are predicted to be exp {kt} higher than initially found. *See* Benson & Magee, *supra* note 54, at 1.

following value growth rates for advances emerging from San Francisco and elsewhere:

Inventions from San Francisco Region

$$VGR = .0155(2012) + .141(4.230289) - 31.197 = 31.186 + .5965 – 31.197 = .5855$$

Inventions from Outside the San Francisco Region

$$VGR = .0155(2012) + .141(2.316428) - 31.197 = 31.186 + .3266 – 31.197 = .3156$$

The difference in VGR figures is .2699, which corresponds to a predicted growth rate for advances emerging from San Francisco innovation that is exp(.2699) or 1.31 times the rate for advances from other parts of the country.

D. *Emphasis on High Value Fields*

San Francisco innovation produces large numbers of advances in fields predicted to have high value growth. As described in the previous Section, technology fields with high mean quick citation values tend to produce high productivity increases (on a per cost basis) and have correspondingly high value growth rates.[104] By using national data on quick citations for all patents published in June 2012, it was possible to identify technology areas with high projected value growth rates and correspondingly high field values. The production of San Francisco advances in high value fields was then compared to similar production elsewhere. This comparison indicated that many San Francisco innovations are adding to (and gaining patent rights in) technical domains projected to have high value growth.

Field values were determined by analyzing mean quick citation counts for classes of technology using nationwide data on patents published in June 2012. The technology classes adopted for this purpose were the primary technology classes and related class definitions used by the USPTO to identify, group, and index related technologies in patent applications and issued patents.[105] This study grouped patents together in accordance with their USPTO-designated classifications in order to

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104. *See id.* at 15.

105. These classifications are contained in the United States Patent Classification System (USPC). *See* U.S. PATENT & TRADEMARK OFFICE, OVERVIEW OF THE U.S. PATENT CLASSIFICATION SYSTEM (Dec. 2012), http://www.uspto.gov/sites/default/files/patents/resources/classification/overview.pdf. As of December 2015, the USPC contained approximately 475 primary classes and 165,000 subclasses. *See Extended Year Set—Patenting in Technology Classes: Breakout by Organization*, USPTO, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/tecasga/explan_torg.htm (last modified Oct. 24, 2017, 1:51 PM).

analyze related sets of technologies. Quick citation means were then determined for each of the technology classes. The technology classes with the largest quick citation means were treated as having the highest projected value growth and highest field values.[106]

San Francisco innovators tended to generate many advances in high-value fields, producing a mix of innovations in the period under study that included a larger percentage of advances in high value fields than inventors elsewhere. This concentration in high value fields is apparent from Table 6, which describes the distributions of patents in the twenty technology classes with the top mean values for quick citations nationwide (taking into account only those classes containing at least 100 patents nationwide). The technology classes are presented in descending order of quick citation means, which corresponds to descending order of projected value growth. For each technology class, the primary class number and nationwide quick citation mean are presented, along with separate figures for the patent count and percentage of all innovations for San Francisco inventions and inventions originating elsewhere:[107]

Table 6:
Technology Mix of High Value Innovations

Primary Class	Class Title	Mean Quick Citations	SF Patent Count	SF Patent Percent	Non-SF Patent Count	Non-SF Patent Percent
717	Data processing: software development, installation, and management	5.800	17	0.96%	88	0.53%
715	Data processing: presentation processing of document, operator interface processing, and screen saver display processing	5.542	28	1.59%	114	0.68%
606	Surgery	5.119	31	1.76%	162	0.97%
623	Prosthesis (i.e., artificial body members), parts thereof, or aids and accessories therefor	4.686	13	0.74%	92	0.55%

106. *See* Benson & Magee, *supra* note 54, at 13.

107. For purposes of this analysis, a patent is considered an "SF Patent" if at least one of its inventors was located in the San Francisco Region and a "non-SF Patent" otherwise.

Primary Class	Class Title	Mean Quick Citations	SF Patent Count	SF Patent Percent	Non-SF Patent Count	Non-SF Patent Percent
726	Information security	4.510	29	1.64%	126	0.75%
704	Data processing: speech signal processing, linguistics, language translation, and audio compression/ decompression	4.311	10	0.57%	93	0.56%
439	Electrical connectors	4.183	2	0.11%	129	0.77%
709	Electrical computers and digital processing systems: multicomputer data transferring	3.583	90	5.10%	277	1.66%
455	Telecommunications	3.513	60	3.40%	529	3.16%
370	Multiplex communications	3.335	99	5.62%	533	3.19%
700	Data processing: generic control systems or specific applications	3.313	6	0.34%	106	0.63%
705	Data processing: financial, business practice, management, or cost/price determination	3.290	47	2.67%	298	1.78%
604	Surgery	3.280	15	0.85%	149	0.89%
382	Image analysis	3.232	52	2.95%	289	1.73%
714	Error detection/ correction and fault detection/recovery	3.229	32	1.82%	147	0.88%
340	Communications: electrical	3.165	13	0.74%	187	1.12%
707	Data processing: database and file management or data structures	3.127	114	6.47%	279	1.67%
701	Data processing: vehicles, navigation, and relative location	3.083	5	0.28%	224	1.34%
362	Illumination	3.055	1	0.06%	127	0.76%
463	Amusement devices: games	3.048	6	0.34%	98	0.59%

All of the indicated quick citation class means are well above the nationwide quick citation mean of 2.499 for all technologies, suggesting that all of these classes have greater than average projected values. For thirteen out of the twenty chosen sets of the classes, the fraction of advances emerging from San Francisco innovators (as indicated by the SF Patent Percent figures) was greater than the fraction emerging from innovators elsewhere (as indicated by the non-SF Patent Percent figures). In five of those thirteen high value technology classes, the fraction of advances emerging from San Francisco innovators was more than twice as large as that elsewhere.

It is impossible to determine from this data whether particular advances within these high value classes will have high value individually.[108] But it is apparent that large fractions of San Francisco innovations—much more than innovations from other sources—are additions to technology fields that are both intense research targets among current innovators (as evidenced by the large numbers of quick citations being made to recent advances in those fields) and likely to have high value growth in the future.

E. High Interest Patent Outliers

Using information on typical quick citation levels for particular technology classes, it was possible to identify innovations within the classes that were standouts in having received exceptionally high interest and atypically large quick citation counts. Standout advances (and their innovators) were identified for diverse technology classes, regardless of whether the quick citation levels for the whole classes were high or low. This analysis identified probable technology leaders in diverse technology areas, as evidenced by the fact that their inventions received exceptionally high interest and recognition within their fields.

108. Where a group of items (here advances within a technology class) have a high mean value for some characteristic when considered as a class (here the mean value for quick citations), this does not necessarily imply that every item within the class has a similar high value. The mistaken attribution of class values to individual class members is sometimes referred to as the "ecological fallacy." *See* DAVID A. FREEDMAN, UNIV. OF CAL., ECOLOGICAL INFERENCE AND THE ECOLOGICAL FALLACY (Oct. 15, 1999), http://web.stanford.edu/class/ed260/freedman549.pdf. A high mean number of quick citations for a technology class is consistent with a diverse range of different quick citation values for specific members of the class. For example, it might be that all members of a technology class with a high quick citation class mean each have a high quick citation count. However, it might also be that a few innovations have extremely high counts while others have only average counts. Either of these scenarios might produce an especially high class mean; it is impossible to tell from a high class mean alone which of these scenarios is correct.

Advances with atypically large quick citation counts were identified in the present study through computation of a Normalized Citation Index (NCI). This technology neutral index measures how much the quick citation count for a particular patented advance deviates from the mean count for all advances in the same technology class. The index takes into account two types of variations in quick citation counts across different technologies: (1) differences in mean levels and (2) differences in typical variations of quick citations within technology categories.

The formula used in determining the NCI is as follows[109]:

$$NCI = (QC - QCMean)/SD$$

Where:

QC = quick citation count (forward citations within three years of publication) for a particular patent

QCMean = mean quick citation value for primary technology class of the patent

SD = standard deviation of quick citations for the primary technology class of the patent

This index is centered on 0 for all technology classes (by subtracting the mean for each class) and scales the variations of quick citations to similar levels across all technology classes (by dividing variations from the mean by the standard deviation for the relevant class). The resulting index measures differences in quick citation counts in units of the standard deviation of counts for all advances in the same technology class. An index value of 0 for this index indicates a patented advance had quick citations equal in number to the mean value of quick citations for all patents in the same technology class. That is, an index value of 0 suggests that the patent has received typical attention for advances of similar technology. A negative value indicates less than typical attention, while a positive value indicates greater than typical attention.

An NCI value of two or greater indicates that the applicable advance received quick citations that were two or more standard deviations higher than the typical mean value for the advance's technology class. Across all technology types, 4.51% of all patents had NCI values of two or more. The percentages for particular technology classes varied but no class containing more than fifty patents had NCI values of two or greater for more than 10% of its patents. Hence, this index provides a good indicator of the top quick citation recipients across

109. The data used in determining the mean and standard deviation figures encompassed the full set of U.S. patents published in June 2012.

diverse technology types. The threshold level of NCI greater than or equal to two was used to flag patented advances with materially elevated citation counts and high interest from current inventors. For purposes of this study, these advances are termed "high interest" inventions.

High interest advances represented almost twice as large a fraction of San Francisco innovations as for advances from other sources. The breakdown of high interest inventions for San Francisco innovations and advances originating elsewhere was as follows[110]:

Table 7:
High Interest Inventions

	SF Inventions	**Non-SF Inventions**	**Total**
High Interest Inventions	133	701	834
Percent Within Region	7.54%	4.19%	
Percent of All High Interest Inventions	15.95%	84.05%	
Other Inventions	1630	16,020	17,650
Percent Within Region	92.46%	95.81%	
Percent of All Other Inventions	9.24%	90.76%	
Total	1763	16,721	18,484
Percent of All Inventions	9.54%	90.46%	

This breakdown illustrates that San Francisco advances much more frequently were standouts in their respective fields (in terms of subsequent interest as measured from quick citations) than advances originating elsewhere. The percentage of high interest advances among San Francisco innovations was almost twice as large as the fraction for innovations emerging elsewhere (7.54% versus 4.19%). Across diverse technologies, San Francisco innovators produced more interesting and potentially influential outliers than innovators elsewhere.

110. For purposes of this analysis, an advance was treated as a "SF Invention" if at least one of its inventors was located in the San Francisco Region and a "non-SF Invention" otherwise.

An analysis of the breakdown of high interest advances for San Francisco innovators versus innovators elsewhere produced similar results as follows:

Table 8:
Inventors with High Interest Inventions

	SF Inventors	Non-SF Inventors	Total
Inventors with High Interest Inventions	341	2153	2494
Percent Within Region	8.56%	4.68%	
Percent of All Inventors with High Interest Inventions	13.67%	86.32%	
Inventors with Other Inventions	3644	43,838	47,482
Percent Within Region	91.44%	95.31%	
Percent of All Inventors with Other Inventions	7.67%	92.33%	
Total Inventors	3985	45,991	49,976
Percent of All Inventors	7.97%	92.03%	

Again, innovators from the San Francisco Region appear to have produced advances receiving high attention from later innovators with much greater frequency than innovators elsewhere.

High interest advances have potential significance in both intellectual and commercial processes. Intellectually, these advances point to domains of exceptionally intense innovation activity. This suggests that the highly cited advances may define technology features or approaches that are important in informing later research or, at least, that the problems addressed in the high interest advances are of continuing strong interest to later innovators. In commercial processes, high interest advances point to potential types of widely used and highly valuable products insofar as the cited advances (or others addressing the same practical problems) solve problems of widespread practical interest and commercial importance. This study's assessment of patent data cannot independently determine whether exceptionally high quick citation counts corresponded to exceptional commercial significance. This will require greater scrutiny of cited advances and their implementations in related commercial products and services.

F. Technology Value as Reflected in Transactional Activity

Transactional acquisitions of patented technologies provide another perspective for studying San Francisco innovation. Patent assignments that occur significantly after the time of related patent applications typically involve changes in ownership of the related technologies.[111] These later assignments are significantly different from the routine employee-employer assignments that transfer rights from inventor employees to their corporate or other institutional employers.[112] Non-employer assignments more commonly reflect technology ownership changes, with the changes triggered by at least some assessment of the value of the technologies being transferred.[113] Technologies subject to non-employer assignments have perceived values at least as high as the cost of the acquisition to the transferee (the party acquiring the technology or at least a recordable interest in the technology).[114] If we can obtain information on non-employer assignments of technologies produced in San Francisco and elsewhere, we can compare the perceived value of these two types of technologies in the eyes of parties engaged in patented technology acquisitions and related non-employer patent assignments.

Fortunately, parties receiving these patent assignments are encouraged to record their transactions, and these records are accumulated in a publically available database.[115] Transfers of patent ownership through assignments are frequently recorded in records filed with the USPTO.[116] Such recordings of patent assignments provide

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111. *See* Alan C. Marco, Amanda F. Myers, Stuart Graham, Paul D'Agostino & Kirsten Apple, *The USPTO Patent Assignment Dataset: Descriptions and Analysis Statistician* 5-6 (U.S. Patent & Trademark Off. Econ., Working Paper No. 2015-2, 2015), http://www.uspto.gov/sites/default/files/documents/USPTO_Patents_Assignment_Dataset_WP.pdf.

112. *See id.* at 7-8 (distinguishing inventor-to-employer assignments of patent rights from inter-firm assignments and noting that the later are "more reflective of the market for technology").

113. *See id.* at 5.

114. *Cf. id.* (noting that patent assignment data may "provide a signal of private patent value" regarding patented inventions by identifying patents that are used to secure financial obligations, licensed, or transferred).

115. *See id.* at 6 (discussing incentives encouraging recording of patent assignments).

116. *See Patents Assignments: Change & Search Ownership*, USPTO, http://www.uspto.gov/patents-maintaining-patent/patents-assignments-change-search-ownership (last visited Oct. 24, 2017).

transferees several legal advantages and assignees consequently have substantial economic motivations to be diligent and complete in recording interest transfers.[117] Because private contracts transferring patent interests would otherwise be confidential (like most private agreements transferring property interests), publicly available USPTO records on patent assignments provide highly important and revealing sources of information on otherwise concealed patent interest transactions and corresponding private recognition of patent value.

Using a dataset on patent assignments maintained by the USPTO,[118] it was possible to select patent assignment data on patented advances considered in this study (that is, advances covered by U.S. utility patents published in June 2012) and determine which of the advances under study were covered by non-employer assignment transactions recorded in the first 2.5 years following patent publication.[119]

Employer assignments involving transfers at roughly the same time as patent issuance were excluded from the assignments considered here. These employer assignments (as identified by the USPTO in its dataset) typically involved intra-organizational transfers from employees to their organizational employers of patent interests gained in the employees' assigned work activities.[120] Such transfers are standard parts of the employment process in research organizations, pre-arranged as a condition of employment.[121] They are significant in establishing formal chains of title, confirming patent ownership transfers from employees to their employers, but do not indicate that the patents transferred were necessarily thought to have particular value when the transfers occurred.[122] Thus, because these types of assignments are not typically based on value assessments of the patented advances they cover, they were excluded from consideration.

The remaining non-employer assignments for the patents were used to determine patent transfer rates for advances emerging from San

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117. *See* Marco, Myers, Graham, D'Agostino & Apple, *supra* note 111, at 6 (noting that, while recording an interest transfer is not mandatory, patent interest transferees have substantial incentives to record patent assignments due to benefits provided the transferees under both the United States Patent Act and federal regulations).

118. *Patent Assignment Dataset*, *supra* note 90.

119. The dataset used in this study included patent assignments recorded with the USPTO through December 2014, approximately 2.5 years following the publication in June 2012 of the patents examined in the study. *See* Marco, Myers, Graham, D'Agostino & Apple, *supra* note 111, at 10 (noting that the USPTO's patent assignment dataset includes information on transactions recorded with the agency between January 1970 and December 2014 (inclusive)).

120. *See id.* at 7-8.

121. *Id.* at 7.

122. *Id.*

Francisco and elsewhere. For purposes of this portion of the study, an advance was considered to be a San Francisco innovation if at least one of its inventors resided in the San Francisco Region. The breakdown of transfer rates for innovations in the San Francisco Region and elsewhere was as follows:

Table 9:
Regional Non-Employer Patent Assignments

Region	Inventions	Percent Assigned
San Francisco Region	1763	23.42%
Outside San Francisco Region	16,721	15.69%

San Francisco innovations were the subject of non-employer transfers much more frequently than their counterparts originating elsewhere, suggesting that these advances were also seen as having value warranting transfers more frequently. The transfer rate for San Francisco advances was (23.42/15.69) or 1.49 times as large as the rate for innovations elsewhere. Thus, perceptions by companies acquiring technologies, as reflected in patent assignments effecting these transfers, further confirm the exceptionally high value of San Francisco innovations.

G. Neglected Innovations

Another measure of invention influence is whether or not an advance has received any quick citations in the first three years after patent publication. The lack of any quick citations suggests that the patented invention involved has not inspired or related to any subsequent research leading to a further patented advance. This provides some indication that the uncited advance is a technological dead end, with no intellectual descendants or offshoots and little influence on subsequent technological development. Advances patented in June 2012 and having no quick citations are referred to here as neglected inventions. The percentage of such inventions in the overall mix of patented advances for an individual or community is an inverse measure of technology influence in that a large percentage of neglected inventions is indicative of a low level of technological influence.

Comparisons of neglected inventions originating in San Francisco versus those elsewhere provides further evidence of the high interest of current innovators in advances emanating from San Francisco. The percentage of neglected patents in San Francisco innovation was markedly lower than the similar percentage for advances originating elsewhere. "Other Inventions" refers to technologies whose patents received at least one quick citation. The percentages of neglected patents for San Francisco and elsewhere were as follows:

Table 10:
Neglected Inventions

	SF Inventions	Non-SF Inventions	Total
Neglected Inventions	552	7444	7996
Percent Within Region	31.31%	44.52%	43.26%
Percent of All Neglected Inventions	6.90%	93.10%	
Other Inventions	1211	9277	10,488
Percent Within Region	68.69%	55.48%	56.74%
Percent of All Other Inventions	11.55%	88.45%	
Total	1763	16,721	18,484
Percent of All Inventions	9.54%	90.46%	100.00%

A parallel analysis of inventors with neglected inventions shows even greater differences between San Francisco innovators and those elsewhere. The fractions of inventors in San Francisco and elsewhere with neglected inventions are summarized below:

Table 11:
Inventors with Neglected Inventions

	SF Inventors	Non-SF Inventors	Total
Inventors with Neglected Inventions	1141	20,055	21,196
Percent Within Region	28.63%	43.61%	42.41%
Percent of All Inventors with Neglected Inventions	5.38%	94.62%	
Inventors with Other Inventions	2844	25,936	28,780
Percent Within Region	71.37%	56.39%	57.59%
Percent of All Inventors with Other Inventions	9.88%	90.12%	
Total	3985	45,991	49,976
Percent of All Inventors	7.97%	92.03%	100.00%

Whether measured on a per patent basis or a per inventor basis, the differences in neglected patents are striking. Advances from outside San Francisco were much more likely to be technological dead ends neglected in later patent applications within the first three years after patent publication. About 13% more patented advances originating outside of San Francisco were ignored than advances from San Francisco. On a per inventor basis, the differences were even greater. About 15% more inventors from outside of San Francisco saw their work ignored than San Francisco innovators did. The lower patent neglect percentages for San Francisco inventions provide further evidence of the frequent influence of San Francisco inventions on later advances.

H. Regression Estimates for Enhanced Influence of San Francisco Innovation

By using linear regression calculations that control for such features as technology types, invention complexity (as measured by numbers of patent claims), inventor collaboration (as measured by inventor group team size), and patent application prosecution delays (as measured by the number of days between the filing of the relevant patent application and issuance of the related patent), it was possible to measure the impact of the San Francisco origins of innovations all of these other factors being equal. In essence, the regression studies eliminated (or at least reduced) the confounding effects of differences in technology mixtures, innovation complexity, innovation collaboration size, and prosecution delays between innovation in the San Francisco Region and elsewhere. The resulting linear regression results were as follows:

Table 12:
Regression Estimate of San Francisco Regional Impacts

Quick Citations	**Coefficient**	**t**	**Beta**
Claim Count	0.06**	15.53	0.12
Inventor Count	0.10**	5.09	0.04
Total Claim Words	0.00**	4.38	0.03
Large Entity	-0.83**	-3.46	-0.03
Non-Employer Assignment	0.50**	4.83	0.04
SF Region	1.31**	8.57	0.07
Prosecution Days	0.00	-1.79	-0.01
Chemical	-0.73**	-4.42	-0.04
Computers & Communications	0.22	1.68	0.02
Drugs & Medical	0.05	0.28	0.00
Electrical & Electronic	0.11	0.75	0.01
Other Technologies	0.22	1.29	0.01
Constant	1.72**	5.64	.

Values marked with "**" were statistically significant at the .01 level (meaning that there was less than a 1% chance that the indicated values resulted from chance variations in underlying processes).[123]

Looking at these regression figures, the location of innovation in the San Francisco Region as opposed to elsewhere was one of the most important indicators of resulting quick citations (and probable invention value as measured from quick citations). All else being equal (among the factors considered in the regression analysis and reflected in Table 12), an advance tended to have about 1.31 more quick citations if made in the

123. The overall predictions of this model were statistically significant at the .01 level with r2 = 0.0295 meaning that factors included in the model explained about 3% of the variations in quick citations.

San Francisco Region rather than elsewhere.[124] This figure may not seem large, but the mean figure for quick citations of all types was a mere 2.50. Elevating a typical advance having this mean value with a 1.31 increment for origination in the San Francisco Region suggests that a typical innovation originating in this region would have a quick citation count of about 3.81 quick citations. This would place the typical San Francisco innovation at about the 80th percentile for advances from all sources (meaning that only about 20% of all advances had similar or higher quick citation counts). Clearly the "typical" San Francisco advance is exceptional advance when seen in the context of advances from all sources.

Another way to consider the importance of the predicted higher levels of quick citations for advances originating in San Francisco is to translate the elevated quick citation estimate into a probable value increase for advances from this region. Using the same methodology previously explained and applied in Section IV.C above,[125] the incremental value growth rate (VGR) associated with the origination of an advance in San Francisco rather than elsewhere is:

$$\begin{aligned}\text{Incremental VGR} &= \text{VGR for SF Innovations} - \text{VGR for non-SF Innovations} \\ &= .0155(2012) + .141(\text{Difference in Mean Forward Citations}) - 31.197 \\ &= .0155(2012) + .141(1.31) - 31.197 \\ &= 31.186 + .185 - 31.197 \\ &= .174\end{aligned}$$

This suggests an incremental value growth rate for San Francisco advances (controlling for differences in technology types, innovation group size, patent prosecution delays, and the other factors mentioned in Table 12) over advances from other sources that is expel(.174) or 1.19 times that of advances from other sources.

This estimated growth rate is similar to but a bit smaller than the estimate of 1.31 times larger for San Francisco advances estimated using

124. The effect seen for location of an advance in the San Francisco Region (corresponding to the SF Region variable in Table 12) was second in impact only to the effect for claim count (comparing these via the beta values for the two variables). Both of these variables had effects that were substantially greater than the other variables considered in the analysis (again basing this conclusion on the substantially lower beta values for the other variables). The effect seen for claim count had a larger beta than that for SF origin, but the size of the coefficient for claim count indicates that a large jump in claim numbers was needed to compare to the impact of San Francisco location. This coefficient (.06) indicated that a patented advance would need to have about twenty-two additional claims (22 x .06 = 1.32) to have a similar predicted impact on quick citation levels as the location of an advance in San Francisco rather than elsewhere.

125. *See supra* Section IV.C; *see also* Benson & Magee, *supra* note 54.

the simpler methodology described in Section IV.C. The estimate of 1.19 times is probably more accurate as the methodology producing it controls for (and largely eliminates) differences in quick citation levels resulting from differences in the technology mixes, innovation processes, and patent prosecution delays for advances from San Francisco and elsewhere.

Even at this slightly lower level, the growth rate for advances originating in San Francisco will produce a much higher estimated value over time than the counterpart rates for advances from other sources. For example, assume two similar advances *A* and *B*, the first produced in the San Francisco Region and the second produced elsewhere. *A* has an estimated value growth rate that is about 1.19 times larger than *B*. After ten years of compounding and value accumulation, the value growth difference for these advances implies that the advance from the San Francisco Region will have a projected value that is 5.69 times greater than its non-San Francisco counterpart.

V. LOCATING SAN FRANCISCO INNOVATORS—THE INNER GEOGRAPHY OF SAN FRANCISCO INNOVATION

Within the San Francisco Region, innovators in different cities exhibited substantial variations in innovation quantities, technology specializations, and innovation influence in the period under study. Up to this point, this Article has described San Francisco innovation as a single phenomenon emerging from a unified regional source. Now the analysis breaks down this source into its geographic components, shifting to an account of innovation patterns within the region. This Part describes the inner geography of innovation within the San Francisco Region and some of the differences in innovation from community to community.

A. Local Invention Production

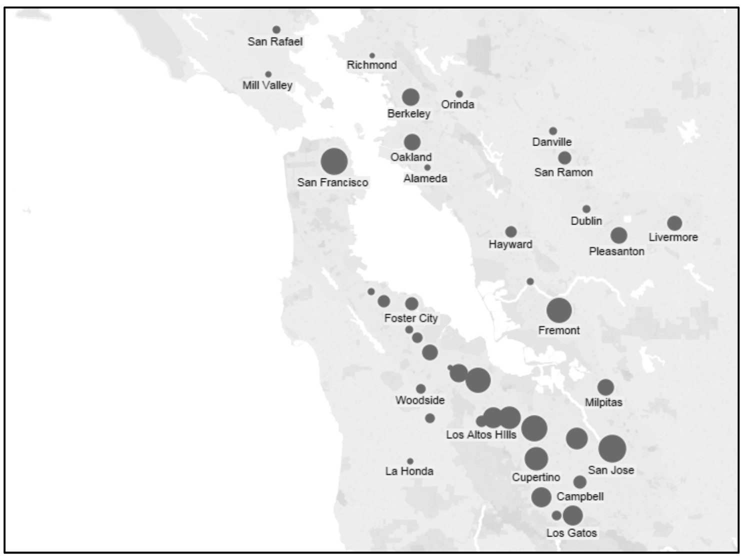
1. Distribution of Inventions

Information on inventor residences as recorded in patents[126] makes it possible to assess where patented advances are produced within the San Francisco Region. For purposes of locating an advance in this portion of the analysis, the city recorded for the lead inventor of a patented

126. *See* 37 C.F.R. § 1.76(b)(1) (2016).

advance[127] was presumed to be the location of that advance.[128] The population figures used in the study reflected the United States Census Bureau's estimates of city populations in 2010 based on the results of the 2010 census.[129] Measured in terms of numbers of patented advances, the top innovation centers within the San Francisco Region were as follows[130]:

Figure 4:
Total Inventions



127. Patents include the city of residence for each inventor of a patented advance (as provided by the inventor) but no more precise location data.

128. This may undercount the number of advances produced by San Francisco innovators since inventions produced in part by San Francisco inventors but having lead inventors located elsewhere will not be counted for communities within the San Francisco Region. For example, an advance produced by two inventors, one located in Princeton, New Jersey, and the other in Berkeley, California, with the former listed as the lead inventor in the relevant patent application and patent, will not be counted as a Berkeley-based advance but will instead be counted as an advance originating outside the San Francisco Region.

This potential undercounting of advances involving San Francisco innovators (but not lead inventors) is avoided in a later analysis that focuses on the features of San Francisco inventors rather than San Francisco inventions. *See infra* Section V.B. In this later analysis, all San Francisco-based inventors are considered (regardless of whether they were lead inventors) and their advances included in innovation counts for cities within the region. *Id.*

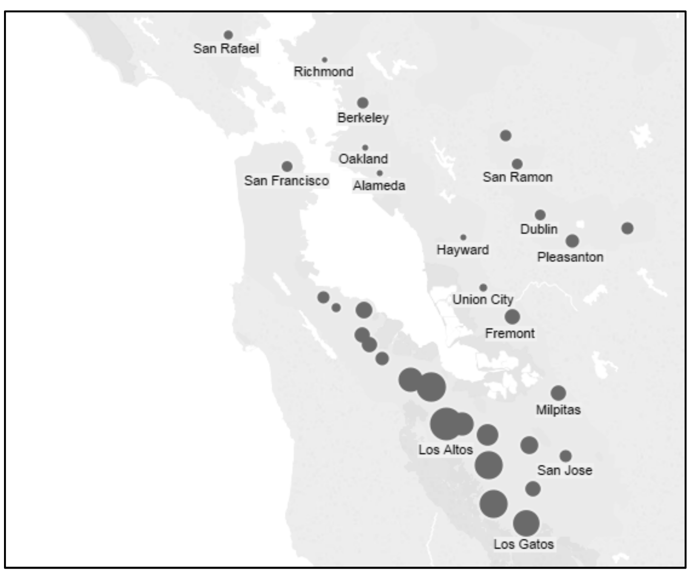
129. *See City and Town Population Totals Tables: 2010-2016*, U.S. CENSUS BUREAU, http://www.census.gov/data/tables/2016/demo/popest/total-cities-and-towns.html (follow "California" hyperlink under "Incorporated Places: 2010 to 2016") (last visited Oct. 25, 2017).

130. This figure reflects advances described in U.S. utility patents published in June 2012, with innovations located by the residence of their lead inventors. Only those cities with five or more patented advances are shown. The maps displayed in the figures throughout this Article were generated with Tableau Public data visualization software. *See* .TABLEAU PUB., http://public.tableau.com/s/ (last visited Nov. 7, 2017).

The dot sizes in this figure correspond to the number of patented advances with lead inventors in the indicated cities (taking into account patents published in June 2012). Some of the cities with the largest numbers of patented innovations are simply the cities with the largest populations (e.g., San Francisco and San Jose).[131] This is an unsurprising consequence of large population size. Large populations will logically tend to involve large numbers of innovators who produce large numbers of patented advances. However, large cities were not the only important sources of patented advances. Much of the output of patented advances emerged from the southern portion of the San Francisco Region from Menlo Park and Palo Alto south. Several relatively small cities in this area (e.g., Cupertino, Fremont, Los Altos, Los Gatos, Mountain View, Palo Alto, and Sunnyvale)[132] had large patent counts almost rivaling the largest cities in the region. This area to the south of Menlo Park and to the north of San Jose is clearly an important engine of patented innovation in the San Francisco Region.

The strength of these smaller cities as innovation sources is even more apparent from an assessment of innovation counts per capita. The following figure displays the number of patented advances per capita for cities within the San Francisco Region:

Figure 5:
Inventions per Capita



131. *See City and Town Population Totals Tables: 2010-2016*, *supra* note 129.
132. *See id.*

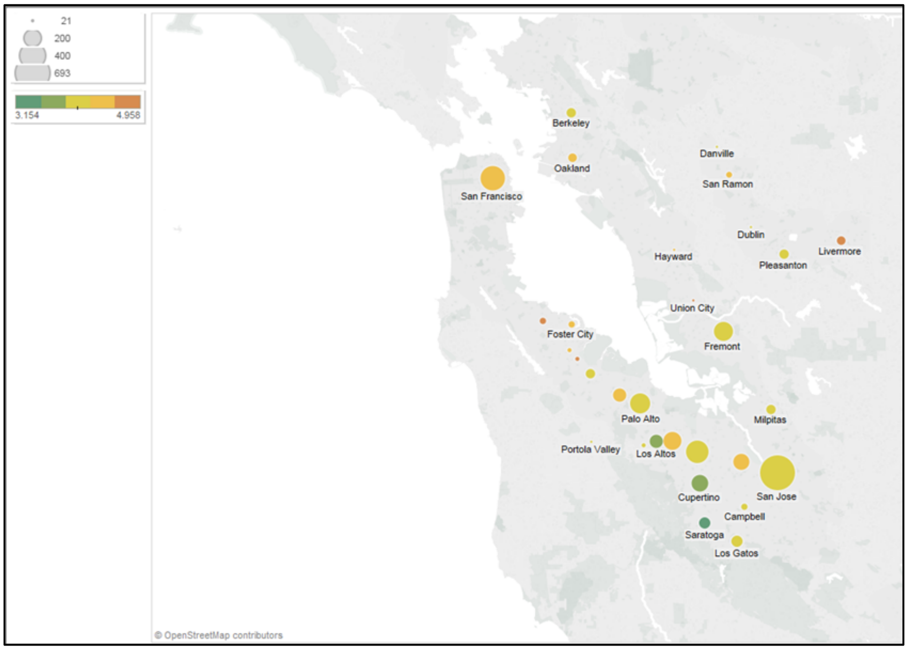
The per capita calculations underlying this figure remove the effects of city size and confirm the importance of innovation in the Silicon Valley area. The dot sizes seen here represent the invention levels expected if all the indicated cities were the same population size. There is a distinctly high concentration of inventions within the Silicon Valley portion of the San Francisco Region. Small cities like Cupertino, Mountain View, Palo Alto, and Los Gatos significantly outproduce (on a per capita basis) larger cities like San Francisco and San Jose. In the latter large cities, diversified economies and workforces may address many commercial and social activities, causing innovation to be a small, diluted portion of local activities. However, in the smaller communities, innovation is likely a much more common and, presumably, centrally important activity. Innovation is fundamentally important both to the companies and other institutions that employ or work with the innovators in these cities and to the local communities that benefit from the wealth generated by the innovators. These small cities are the San Francisco Region's concentrated sources of innovation with the highest local rates of per capita innovation.

2. Distribution of Inventors

A better sense of local concentrations of inventors within the region can be gained from evaluations of inventor numbers in different cities. Differences from city to city in numbers of inventors can be seen from maps displaying the locations of all inventors within the San Francisco Region who contributed to patented advances regardless of whether they served as the lead inventors for the advances. The locations for inventors contributing to advances covered by patents published in June 2012 (including only cities with at least twenty inventors)[133] were as follows:

133. This limitation was imposed to simplify the illustration; without it, the number of cities with dots would be so extensive as to confuse the presentation.

Figure 6:
Inventors and Team Size



In this figure, the dot sizes for the cities reflect the number of inventors located there, while the colors of the dots reflect the average team sizes for inventors in the cities.[134]

Several interesting features are shown in this figure. First, as with the distribution of inventions, large cities (San Francisco and San Jose) top the inventor totals. The cities with the largest inventor counts (reflecting all cities in the San Francisco Region with 100 or more inventors of advances patented in June 2012) were as follows:

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134. The team sizes used for determining these colors reflected the full teams contributing to particular advances regardless of the overall team locations. For example, if a patented invention was produced by a five-member team involving one Palo Alto resident and four parties residing elsewhere, this was treated as a five-member team associated with a Palo Alto inventor.

Table 13:
Top Inventor Counts by City

City	Inventors	Percent of Inventors in Region
San Jose	693	17.39%
San Francisco	352	8.83%
Sunnyvale	300	7.53%
Palo Alto	242	6.07%
Fremont	220	5.52%
Mountain View	199	4.99%
Cupertino	174	4.37%
Santa Clara	163	4.09%
Los Altos	124	3.11%
Menlo Park	117	2.94%
Total for SF Region	3985	100.00%

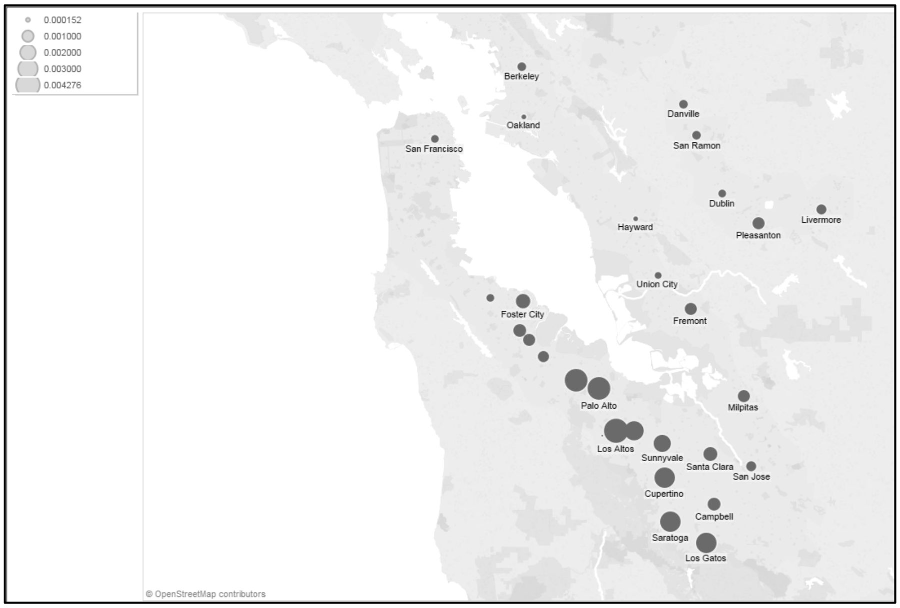
A clear distinction in inventor counts is apparent between the areas surrounding the two major research universities in the region—University of California, Berkeley (UC Berkeley) and Stanford University. The Berkeley area accounted for relatively few inventors (sixty-three) as did nearby Oakland (sixty-two). Some of the 352 inventors living in San Francisco may be researchers at UC Berkeley (or at University of California, San Francisco, the medical research facility operated by the University of California in San Francisco). However, even if all of these San Francisco researchers are added to Berkeley's totals, the count is far lower than the aggregate number of inventors in the vicinity of Stanford. The combined inventor counts for the five communities closest to Stanford (Palo Alto, Menlo Park, Mountain View, Los Altos, and Sunnyvale) is 982, which is more than twice the total for San Francisco, Berkeley, and Oakland combined (477). Thus, while both are anchored by major academic institutions, the region surrounding Stanford far outdistanced that surrounding UC Berkeley in numbers of inventors.

Looking at average team sizes for inventors producing patented advances (indicated by the colors of the dots for various cities in Figure 6), some city-specific innovation differences within the San Francisco Region start to emerge. The average team size for Cupertino, for instance, was smaller than for most of the other cities shown. This may reflect the dominance of software-oriented innovators in this city (many of them working for Apple Corporation) and the ability of such innovators to work effectively on software-based advances in smaller groups (on average) than their counterparts focused on hardware advances or complex biology or chemistry projects. In contrast, innovators in Livermore seem to have worked in teams having a larger average size than in most other cities, perhaps reflecting some of the complexity of the atomic energy, optics, and materials science projects and advances emerging from the nearby Lawrence Livermore National Laboratory.

These revealed variations in local team sizes begin to hint at the potential value of studying innovation characteristics in specific cities. Examination of community patterns may reveal, for example, that large teams are especially common in a particular city (even if inventions from that city cover a number of different technologies or are produced for a number of different employers). Where this is the case, it may be valuable to target supportive resources in light of these team characteristics and probable team needs. Team or project management software or team leadership training may be particularly valuable (and well received) in these settings. Similarly, if particular cities are sources of many projects concerning specific technologies, it may be worthwhile for nearby companies to provide supporting resources, training, services, and even personnel with specialized skills that are relevant to that set of technologies. The targeting of various resources (and resource providers) in this way will not only create additional commercial opportunities for the resource providers but will promote the research and product development of the innovators in the targeted locations. These innovators will gain abilities to complete more research and produce more patented advances as their work and results benefit from increased support.

As was true for numbers of inventions, raw numbers of inventors for specific cities are heavily influenced by the overall population sizes of the cities. Evaluations of numbers of inventors per capita offer better insights into local innovator concentrations across cities of various sizes. The per capita distribution of inventors within the San Francisco Region (for inventors contributing to advances patented in June 2012) was as follows:

Figure 7:
Inventors Per Capita



Dot sizes in this figure reflect the numbers of inventors per capita in the indicated cities. This figure paints a somewhat different picture of the heartland of inventive activity in the San Francisco area. On a per capita basis, inventors form much more substantial fractions of the population in the Silicon Valley area at the south end of the region than elsewhere. Large population centers like San Francisco, San Jose, and Oakland have relatively small numbers of inventors measured on a per capita basis. A number of medium sized cities such as Fremont and Santa Clara are also dwarfed in innovator populations by a few small communities.

The cities in the San Francisco Region with the largest per capita inventor concentrations were:

Table 14:
Top Cities in Inventors Per Capita

City	Inventors per Capita
Los Altos	.004276
Palo Alto	.003757
Menlo Park	.003653
Saratoga	.003036
Cupertino	.002971
Los Gatos	.002820
Sunnyvale	.002142

By contrast, cities in the region with relatively large populations had much lower numbers of inventors per capita:

Table 15:
Large Cities—Inventors Per Capita

City	Inventors per Capita
San Jose	.000728
Berkeley	.000560
San Francisco	.000437
Oakland	.000159

Since these per capita figures equalize the analysis of inventive communities across large and small cities, they arguably provide better indicators of the heartland of innovation in the San Francisco Region than raw inventor counts. The per capita figures certainly confirm that inventors (at least those accounting for patented advances) are a much greater percentage of local populations in several communities near and to the south of Stanford University than anywhere else in the region.

Even in the City of San Francisco, an area regarded by some as the second most significant innovation center in the region after the Silicon Valley area near Stanford, innovators form a relatively small component of the population, an order of magnitude smaller than the per capita levels for the Silicon Valley communities noted above. The impacts of innovators on San Francisco life styles and living costs have received much attention of late,[135] but innovators form much larger components of communities in Silicon Valley and are likely to dominate to a greater extent there accordingly. Innovators in San Francisco form a very small fraction of this still highly diversified city and its large economy.

The real hotbeds of innovation—locations of intense community focus on innovation and the areas in which innovators and nearby innovating companies will continue to have the greatest influence and impacts—seem to be in cities near Stanford and to the south as far as Cupertino and Los Gatos. These communities contain large fractions of innovators, implying that the needs of innovators are correspondingly important in these settings.

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135. *See, e.g.,* Carol Pogash, *Gentrification Spreads an Upheaval in San Francisco's Mission District*, N.Y. TIMES (May 22, 2015), http://www.nytimes.com/2015/05/23/us/high-rents-elbow-latinos-from-san-franciscos-mission-district.html?mcubz=1; Joe Garofoli & Carolyn Said, *A Changing Mission: To Whom Does San Francisco's Oldest Neighborhood Belong?*, S.F. CHRON. (Oct. 17, 2017), http://www.sfchronicle.com/the-mission/a-changing-mission/.

The prevalence of innovators in these communities points to several sets of corresponding business opportunism. Innovators in these communities will have needs for research support, implying business opportunities for companies supplying items and services aiding in research activities. In addition, innovators in these communities will create business opportunities for parties that cater to the individual consumer purchases of the frequently affluent and highly educated innovators.

Of course, the figures in this Article reflect inventor distributions as of June 2012. But many of yesterday's innovators (as reflected in the figures and data analyses presented here) are also tomorrow's key researchers. Accordingly, the communities near Stanford, identified here as having large per capita inventor populations in 2012, should continue to have concentrated needs and potential for companies providing research-related products, training, and services.

B. Local Technology Specialization

Another interesting result of the study was the showing that the certain communities with large concentrations of specialized inventors focused on a particular class of technology. These local specializations are important since they suggest both the types of further advances innovators in particular cities are likely to produce and the specialized resource needs of those communities in pursuing future advances. The scope of the data assessed here (from patents published in June 2012) does not permit highly detailed breakdowns of technology strengths for specific cities because most communities have too few patents in particular technology areas for specialization assessments to be possible. However, it was possible to assess local distributions of inventor specializations for some of the most prevalent types of technologies.

Local inventor specializations were evaluated for the ten technology classes having the largest numbers of patents published in June 2012. Inventor counts for cities in the San Francisco Region were determined for each of the ten classes of technology as identified by the USPTO.[136] The geographic distributions of inventors for the ten most frequent technologies (in descending order of frequency) are shown in the following figures. The dot sizes in these figures indicate the number of

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136. The technology classes included here are primary technology classes defined by USPTO and used to classify patent applications and issued patents. The class titles contained in the figures were assigned by the USPTO and indicate the types of technologies involved. The ten most prevalent technologies were determined from nationwide class totals for advances granted patents in June 2012.

inventors in the cities that produced advances in the listed technology areas (showing only cities having at least five inventors producing advances in each technology class):

Figure 8:
Class 370: Multiplex Communications

Figure 9:
Class 455: Telecommunications

Figure 10:
Class 257: Active Solid-State Devices
(e.g., Transistors, Solid-State Diodes)

Figure 11:
Class 514: Drug, Bio-Affecting and Body Treating Compositions

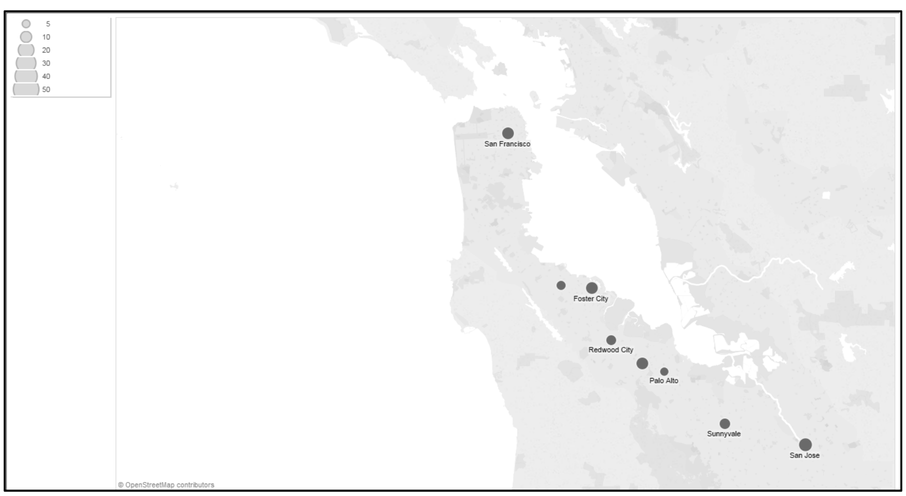


Figure 12:
Class 707: Data Processing: Database and File Management or Data Structures

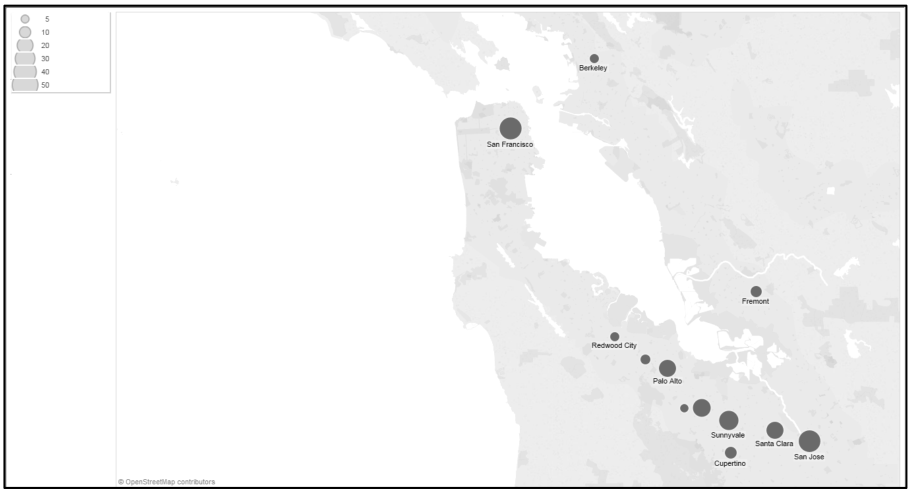


Figure 13:
Class 345: Computer Graphics Processing and Selective Visual Display Systems

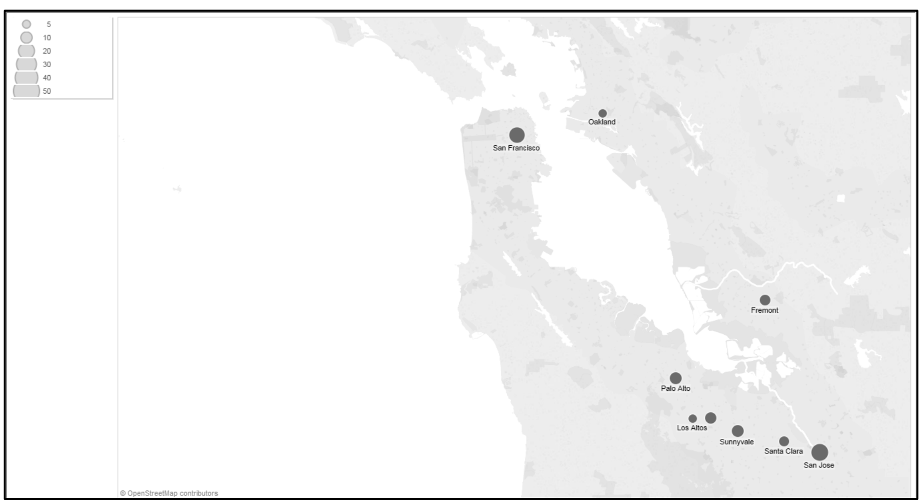


Figure 14:
Class 709: Electrical Computers and Digital Processing Systems:
Multicomputer Data Transferring

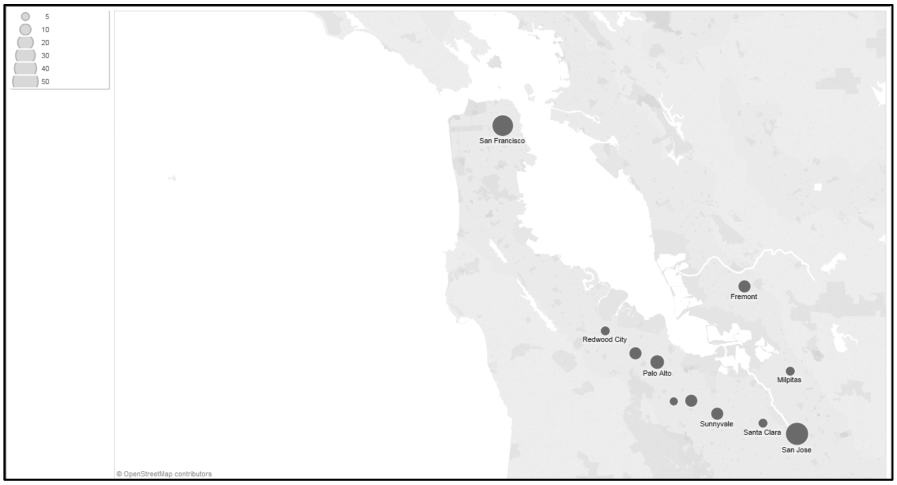


Figure 15:
Class 438: Semiconductor Device Manufacturing: Process

Figure 16:
Class 705: Data Processing: Financial, Business Practice, Management, or Cost/Price Determination

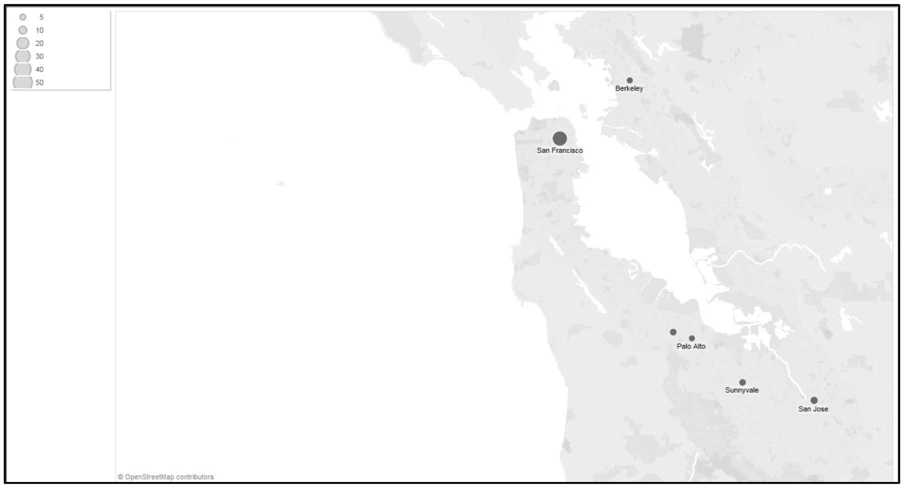


Figure 17:
Class 382: Image Analysis

These inventor distributions identify distinct technology specializations within portions of the San Francisco Region. Further assessments of local technology variations—undertaken via studies conducted at the community level and over longer time periods—may refine the preliminary analyses presented here. Additional studies may reveal the technology production mechanisms accounting for the specialization differences shown in these figures. Community-specific studies may, for example, identify local technology interests or local employment patterns that account for technology strengths in particular cities. These studies may also be able to determine if local patterns of specialization in patented research are accompanied by other research (perhaps protected by trade secrets) in the same technology areas.

More analysis will also be needed to determine if the local technology specializations seen here hold true over time and, if there are changes, the factors that drive those changes. Patterns of local specialization may be tied to the presence of particular employers and related research facilities in or near some cities. If so, technology strengths for particular cities should be relatively stable (tracking the presence of these key employers near the cities). Even where a particular employer or institution dominates nearby innovation, the research agendas of the employer or institution may change over time, in which case the local specialization of inventors should change accordingly.

Local technology strengths and specialization may also change in response to broader changes in industry characteristics or engineering knowledge. Different types of technologies may be "ripe" for advances in specific years, resulting in new "hot technologies" reflected in increases in the quick citations for cities that can respond to the ripe technologies. If this is the case, the mix of technologies emerging from innovators in a single city might change substantially from year to year, but the rise and fall of technologies for particular cities should parallel similar changes at the national level (since most innovators working in the same field will see the same pressures and opportunities for innovation within a given field of technology).

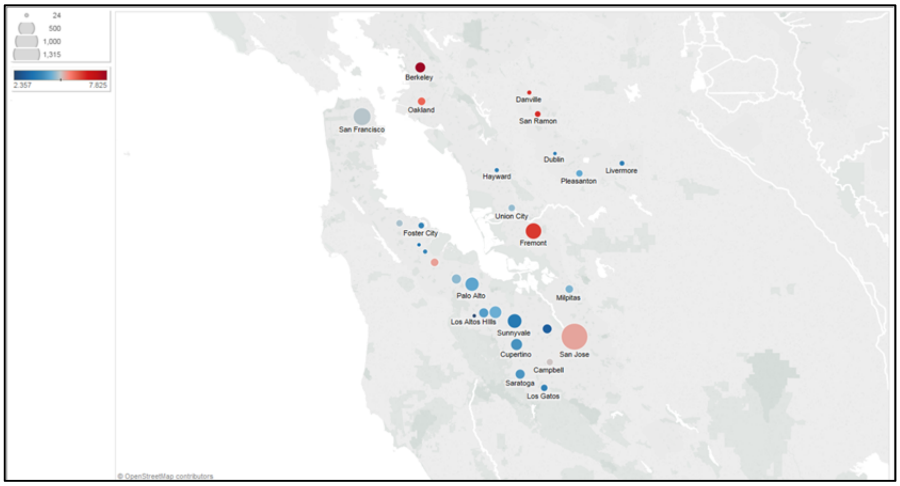
Evaluations of these (and other) mechanisms driving local technology specializations will depend on additional data describing patented advances over longer periods and on further examinations of the local circumstances and personnel driving technology development. Evidence of local technology differences as shown in the figures above are the starting points for these studies, providing initial insights into potential local specializations that can be confirmed by more detailed attention to local technology development processes.

C. Local Innovation Influence

Quick citation counts also pointed to differences in the influence over technology development of innovators residing in specific cities within the San Francisco Region. To study these influence differences, total allocated quick citation figures were determined for each city in the

San Francisco Region having at least twenty quick forward citations. The resulting local distribution of allocated quick citations (and corresponding distribution of local influence on later innovation) was as follows:

Figure 18:
Total Allocated Quick Forward Citations



The dot sizes in this figure correspond to the total number of allocated quick citations for inventors in each city (that is, the sum of allocated quick forward citations for all patents published in June 2012). These dot sizes reflect estimates of the total influence on subsequent patented innovations of inventors in these cities.[137] The dot colors indicate the mean quick citation values for specific cities, with colors at the extreme red end corresponding to relatively high mean values (and relatively high influence for patented advances from that city) and those at the extreme blue end indicating relatively low mean values (and relatively low influence for patented advances from that city). The dot colors are based on per-invention mean values rather than allocated quick

137. Where multiple inventors worked on one invention, the quick citations for that invention were allocated to each inventor. Thus, for example, if a team of three inventors produced an advance that received six quick citations, two quick citations were allocated to each of the three inventors. The inventors in the San Francisco Region producing all of the advances in the study were then grouped by cities and the aggregate allocated quick citations totaled for each city. This set of computations involved two attribution steps: the first allocating invention influence indicators (as measured by quick citations) fractionally among members of innovation teams and the second allocating (through aggregation of the allocated quick citations for all residents) to particular cities, thereby estimating the overall community influence of the inventors in those cities.

citations attributed to individual inventors. Per-invention mean values were used to reflect the average influence of advances emerging from the indicated cities.

Berkeley-based innovation presents interesting features here. While the total number of allocated quick citations for advances produced by Berkeley residents was small (as indicated by the small dot size for the city), the mean quick citation count was particularly high (as indicated by an intense red color of the dot for Berkeley). Residents of several other cities (particularly Fremont, Danville, and San Ramon) also produced advances with relatively high quick citation means and apparently high influence per innovation (as reflected in the red dots for those cities). By contrast, residents of several medium-sized cities (including Los Gatos, Santa Clara, and Sunnyvale) seem to have produced advances with relatively low influence per advance (as indicated by the dark blue dots for these cities).

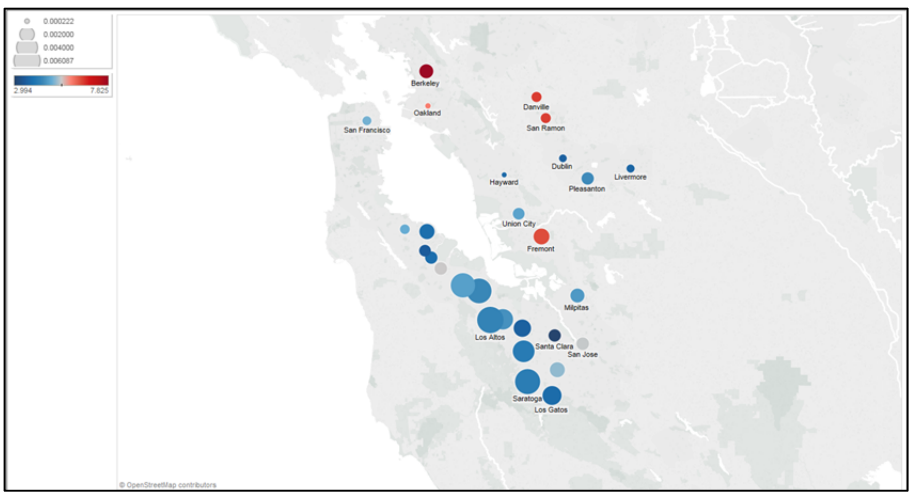
These differences in mean citation levels may result from several underlying mechanisms. First, innovators in some cities may consistently produce advances that are especially important to subsequent technology development, resulting in larger mean quick citation counts accordingly. Under this view, it would worthwhile to know more about the advances being produced in a city with high influence per advance (e.g., Berkeley) and how those differ (both in substance and in relevance to later innovation) from advances in the same time period produced by innovators in another city with seemingly lower influence per advance (e.g. Santa Clara).

Second, mean quick citation differences from city to city may reflect differences in the substantive technology mixes of advances emerging from different cities. If innovators in one city work primarily in a technology field with generally high quick citation counts and innovators in a second city work primarily in a different field with generally low quick citation counts, the mean count for innovators in the first city will tend to be higher than the mean count for innovators in the second city. Whether or not this is a factor can be determined by assessing mean citation levels for cities while controlling for the technology mixes of the advances scrutinized. The size of the data set used in the present study did not allow for this type of control to be exerted as the number of advances in particular city-technology combinations was too small.

Whether these—or other—mechanisms account for the city-to-city differences seen in mean citation counts will require further studies of innovation practices city by city. The differences shown in the above figure suggest that these studies may be worthwhile, particularly to determine the basis for the large per innovation influence of inventors living in cities like Berkeley and to assess whether similar high influence factors can be replicated in other communities.

Cities in the San Francisco Region with large populations generally had large numbers of allocated quick forward citations as shown in the last figure. To eliminate the effects of city population size, per capita values were calculated for total allocated quick citations in each city. The resulting per capita distribution of allocated quick citations (considering only cities with at least twenty quick forward citations) was as follows:

Figure 19:
Total Allocated Quick Forward Citations Per Capita



Dot sizes here reflect the total number of allocated quick citations per capita for each city. Dot colors correspond to the mean quick citation values those cities.

Especially high per capita counts (and projected influence) for cities in the Silicon Valley area (including cities from Menlo Park south) are apparent from this figure. The dot sizes for the cities in this portion of the San Francisco Region are consistently the largest, indicating relatively large technology influence for advances from these cities (controlling for population size). However, even though these cities produce advances with a large aggregate influence (as indicated by large allocated quick citation totals), the influence per advance appears relatively small (as indicated by the blue color of the dots for these cities and their corresponding low mean citation values). This suggests that inventors in Silicon Valley and south to Los Gatos are high volume innovators, but that advances from other cities in the San Francisco area have greater influence on a per advance basis.

A comparison of advances from Silicon Valley to those from Berkeley is particularly revealing. Advances from innovators in the vicinity of Stanford University and south to Los Gatos received more allocated quick citations (and probably had more aggregate impact) on a per capita basis than corresponding advances from innovators living in the vicinity of UC Berkeley. In contrast, innovators living in the Berkeley area seem to have had greater influence per advance (as indicated by the deep red color of the dot for Berkeley corresponding to a relatively high mean quick citation value).

Each of these measures of innovation success has some appeal. Silicon Valley advances (or at least advances with patents published in June 2012) seem to have the greatest total influence, which is certainly an important measure of overall impact.[138] The higher total levels of quick citations from innovations created in these cities also suggests a higher overall future invention value.[139] But Berkeley-based advances have achieved a different type of success, reflecting more intense influence per advance which may correspond to more "efficient" innovation with fewer projects each producing advances with greater importance per project.[140]

VI. FUTURE STUDIES—THE VALUE OF QUICK CITATIONS

Quick citations and the related analytic techniques described in this study of San Francisco innovation should be useful tools for additional analyses. This Part briefly describes some of the useful extensions of the analyses presented here and the ways that these extensions would complement the present study's findings.

A. Innovators

One useful line of further inquiry would be to extend this study's findings to examine the work of influential innovators (as indicated by high quick citation counts) over time. A number of questions might be addressed in these studies. What, if any, are the distinctive practices and research associations of these influential inventors? Do these influential

138. *See* Hall, Jaffe & Trajtenberg, *supra* note 25, at 34.

139. *See id.*

140. Projects with these characteristics would be more "efficient" in the sense of producing more influence per project than in communities with lesser influence per project.

innovators tend to produce strings of influential inventions over time, suggesting that they are particularly effective in both solving practical problems (as indicated by their continuing pattern of patented inventions) and in producing solutions that are of high interest to later innovators (as indicated by their consistently large quick citation counts)?

Also, do influential innovators tend to work with stable innovation teams over time (as indicated by repeat inventions produced by the same or similar teams of inventors), or do influential inventors work with varying groups over time? How do the patterns of team membership and changes for influential inventors (that is, inventors with high quick citation counts) compare to those for all inventors? To the extent that team members come and go (that is, there is not a stable set of team members who account for multiple patents), do influential team members (with high quick citation counts) tend to team up with other parties with high quick citation counts and likely high influence in accordance with Steve Job's observation that A-team innovators generally want to work with other A-team innovators?[141]

B. Institutions

This study found that innovators in some cities within the San Francisco Region have produced inventions with much more influence (as measured from quick citations) than innovators elsewhere in the Region. An extension of this study might seek to relate these city-specific findings to particular institutional sources within or near cities. For example, looking at university influences, it should be possible to examine patents emerging from major academic institutions such as Stanford University; the University of California, Berkeley; and the University of California, San Francisco, and determine if the advances covered by these patents appear to have had more influence than those of other academic institutions or more than patented innovations generally.

It should also be possible to identify the technological strengths of various academic institutions (by examining the technology mixes of patents emerging from the institutions) and to determine if the academic institutions appear to have strong influence in their areas of technology strength (by examining whether the institutions have high quick citation counts in fields where they are producing large numbers of patents). It will also be possible to determine if specific universities are producing patented advances that appear to be of little interest to later innovators, as

141. *See* WALTER ISAACSON, STEVE JOBS 181 (2011).

indicated by high percentages of neglected patents emerging from particular institutions.

Similar studies might address differences in innovation success and influence of major companies backing innovation in the San Francisco Region. By relating patents issued to San Francisco innovators to their technology companies (such as Google, Apple, Intel, and other major technology companies that are the major private employers of scientists and engineers in the region), the relative success and influence of these commercial institutions can be evaluated in terms of both patent counts and related quick citation levels.

A different sort of corporate analysis might examine technology acquisitions by large corporate entities. By looking to non-employer patent assignments as indicators of technology acquisitions, it should be possible to track acquisitions of patented technologies by large firms.[142] By assessing whether these transfers tend to focus on influential technologies with large quick citation counts, we can gain new insights into technology acquisitions and related technology valuations.

C. Innovation Geography

This study's methods can also be extended to address other geographic features of innovation processes. Past research has suggested that technologies are developed and advanced by clusters of innovators with similar interests who benefit from face-to-face interactions with their fellow specialists and gain knowledge spillovers from other specialists' advances.[143] Extensions of the present study can evaluate how often successful producers of patented advances cluster together, as well as the types of technologies most produced by clusters of innovators.

Further studies building on the present project may aid understanding of the sources of innovator clustering. The reasons accounting for the clustering of innovators within close proximity are still poorly understood. For example, even where clusters of innovators are found, these clusters may be no more than artifacts of employment practices of particular large companies having research agendas that

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142. Where independent parties are involved (as opposed to related companies shifting patents between themselves), patent assignments to large companies are effectively purchases of the technologies involved, shifting ownership from the companies and independent inventors that have developed and patented the technologies.

143. Clusters of innovators with related specializations and technology interests can be advantaged by their proximity in many ways. These advantages include input sharing in research, labor market matching, and knowledge spillovers. *See, e.g.*, Gerald Carlino & William Kerr, *Agglomeration and Innovation*, *in* 5 HANDBOOK OF REGIONAL AND URBAN ECONOMICS 349, 366-72 (Gilles Duranton, Vernon Henderson & William Strange eds., 2015).

attract and co-locate innovators with related technology specializations. The prevalence of these practices can be tracked by identifying groups of patents transferred to particular large companies via assignments from employees and then determining whether the inventor teams producing these advances are composed (or at least mostly composed) of inventors residing close to major research institutions maintained by the companies involved.

Another interesting question for further study using the techniques of the present project is whether any city in the San Francisco Region (or elsewhere) produces unusually large numbers of advances or unusually influential advances across multiple technologies, suggesting generally favorable conditions in that city or region for diverse types of innovation. If so, the innovation enhancing features of the community and its surroundings would be highly interesting, particularly if they could be transferred to other communities with diverse technology development projects and interests.

One final consideration for further study would be whether, in a city that has a particular technology strength (as shown by large patent numbers) or high influence within an area of technology (as shown by a high mean quick citation level for that technology), the strength is usually accounted for by one particularly successful institutional employer (e.g., a company or academic institution nearby that accounts for most of the local employment of innovators) or instead stems from multiple employers, suggesting that some other shared factor in the community accounts for its peculiar technology strength or influence.

D. Predicting Hot Tech

Perhaps the most intriguing question raised by the present study is whether particular high value technologies can be predicted using quick citations. While we know from prior research that quick citations (in combination with further information on the age of patents used in the evaluations) are good predictors of value growth across entire fields of technologies,[144] we do not yet know if this relationship between quick citations and invention value holds at the per invention level. Further study is needed to determine if quick citations are useful predictors of "hot tech" invention by invention—that is, to evaluate whether quick citations can predict specific inventions with large future technology development interest and probable value growth.

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144. *See* Benson & Magee, *supra* note 54.

It seems possible that the crowdsourced indications of technology interest and influence measured via quick citations will prove to be good indicators of likely commercial success and societal impact of particular inventions. Quick citations may point to "hot tech" at the invention level because technologies with high quick citation counts (or at least exceptionally high counts for their fields as indicated by factors like high NCI indexes) are especially likely to have large commercial responses and widespread adoption in later products and services.

By measuring quick citations for specific inventions and then tracing how inventions with high quick citation counts fare in later products and services, it should be possible to determine if quick citations (either alone or in combination with other measurable characteristics) provide useful means to predict hot technologies based on the crowdsourced "votes" of confidence and interest of the innovators who provide information captured in quick citations.

At present, the meaning of high quick citation counts is still uncertain. High quick citation counts may measure features other than the value of the cited technologies, such as the intensity of later innovators' interest in similar fields or similar problems. It may be that particular advances with high quick citation counts generally form the bedrock for further rounds of innovation, in which case high quick citation counts for specific inventions should correlate with invention value and subsequent adoption. However, high mean quick citation counts for entire classes of technologies may correlate with value growth because advances in that class (including the advances covered by both the cited and citing patents) reflect a new underlying approach or breakthrough, but the value may not stem from the inventions covered by the cited patents. Or high mean quick citations for advances in a field may indicate that there is intense interest by recent innovators in the field to solve a particular practical problem or fill a particular need, resulting in many citations to earlier patents that have addressed (not necessarily successfully) the same practical problem or need. Which of these implications of high quick citation averages holds true is one of the key topics for future research using patent records and associated quick citation patterns.

VII. CONCLUSION

Careful examination of inventor locations, technology specializations, and innovation influence provide new insights into the features and geographic variations of innovation in the San Francisco Region. Innovation in the San Francisco Region is different in several important ways from technology development in the rest of the country. Innovation teams are more prevalent and larger in the San Francisco Region than elsewhere; advances in San Francisco emphasize technology fields with intense research activity and high predicted value; and advances with exceptionally large influence on later research are especially prevalent in San Francisco.

Local patterns of innovation specialization and influence appear to vary greatly within the region, however. Certain technologies are heavily represented in advances from specific cities. Areas surrounding major research centers (specifically UC Berkeley and Stanford University) have very different innovation outputs, with inventors in the vicinity of UC Berkeley producing relatively few patented advances having high influence per advance, and inventors in the areas surrounding Stanford producing far more advances on a per capita basis but with each advance having less influence.

Conclusions about these and other features of San Francisco innovation are necessarily tentative due to limitations of the current study to data from patents published in a specific period and the forward citations to those patents over the three years subsequent to patent publication. Additional data covering more advances and lengthier periods will enable more certain and more detailed conclusions about the features of San Francisco innovations and innovators. Data extending over longer periods will support assessments of whether innovation differences found here are stable over time. Data addressing longer time intervals will also permit evaluations and comparisons of track records of innovators over multiple innovation projects. These assessments will support a variety of studies of inventors' values and behaviors, including assessments of whether inventors having large or small influence in their early advances tend to have the same influence in later advances and whether inventors who produce innovations with high influence tend to group with other inventors of similar background in working on subsequent innovations.

These and other studies of regional characteristics and inventor behaviors concerning technology development are enabled by the valuable crowdsourced information available in patents and patent citations. By treating forward citations (and particularly quick forward citations within three years of patent publication) as measures of innovation influence and potential innovation value, important new studies of innovation sources, regional trends, and innovator behaviors are now possible.