THE EVOLUTION OF COLLABORATIVE INVENTION AT A DISTANCE: EVIDENCE FROM THE PATENT RECORD

by

Richard S. Gruner*

Many forces now drive technological advancement through group innovation. Increasingly, group innovation projects involve efforts to combine globally dispersed expertise and to advance invention processes among working groups separated by great distances. Administrative resources embedded in worldwide corporate organizations and improved communication infrastructures such as the Internet draw together and facilitate new efforts to innovate through globally dispersed workgroups.

---

* Richard Gruner is the Director, Center for Intellectual Property Law and Professor of Law at the John Marshall Law School in Chicago. He is a registered patent attorney and a former inside counsel to the IBM Corporation. Professor Gruner is a member of the New York and California bars and a graduate of the University of California, Irvine (PhD. 2008), Columbia University School of Law (LL.M. 1982), the USC Law School (J.D. 1978), and Caltech (B.S. 1975). His books include Intellectual Property in Business Organizations: Cases and Materials (LexisNexis 2006), co-authored with Shubha Ghosh and Jay Kesan, and Intellectual Property: Private Rights, the Public Interest, and the Regulation of Creative Activity (West 2007), co-authored with Shubha Ghosh, Jay Kesan, and Robert Reis.

The author wishes to thank Timothy M. Cho for his substantial contributions to this project while acting as the author's research assistant.

There are several reasons why increases in geographically dispersed work groups may produce more or better innovations. Research groups assembled worldwide may produce quicker or more effective innovation by simply involving more designers with parallel skills in innovative tasks. These groups may also be advantageous because they apply complementary expertise or skills held by parties in different countries and regions to shared design tasks. Where parties in different countries or regions have significantly different expertise (in number or in kind), joint efforts of parties from multiple countries or regions may be particularly important in bringing the right mix of expertise to bear in certain lines of innovation development.

The growing importance of innovation projects involving physically separated groups of employees or researchers has created an associated need for new means to coordinate and promote efforts of designers interacting at a distance. Recent research has emphasized the surroundings and practices at both individual and organizational levels that can make collaborative interactions effective, particularly in advancing engineering research and development and other new design efforts.[1]

---

1 *See, e.g.,* Arvind Malhotra & Ann Majchrzak, *Virtual workspace technologies: emerging technologies enable virtual and distributed teams to communicate -- and innovate -- more effectively*, 46 MIT Sloan Management Review 11 (2005); Richard R. Reilly & Michael Ryan, *Leadership in Virtual Teams*, Howe School Forum (Spring 2007), http://howe.stevens.edu/fileadmin/Files/News___Events/howe_forum/Leadership_in_Virtual_Teams.pdf; Charles Steinfield, Chyng Yang Jang, Marleen Huysman, & Kenneth David, *Communication and Collaboration Processes in Global Virtual Teams*, http://www.cscw.msu.edu/papers/INTEnD_Summary.pdf.

Appropriately enough, innovation groups are addressing the problem of how to form and conduct innovation groups. For example, a patent on a method for promoting the formation and operation of such groups was issued in late 2008. *See* United States Patent No. 7469384, "Method and System for Creating a Virtual Team Environment" (December 23, 2008). The creators of this patented invention appear to have practiced what they preached. The patent emerged from

The challenges facing parties who seek to form and administer effective innovative workgroups are considerable. One group of analysts described these challenges as follows:

> The knowledge economy is fundamentally affecting the modern work environment. As demand for knowledge workers increases, new work paradigms are being developed in which specialized teams are assembled for specific projects. Those specialized teams may need to work together for a matter of days, weeks or months to accomplish a given project. With more regularity, the team is disbanded after the project is completed and team members move on to other projects, often working with a partly or completely different group of people. In addition, people who need to work together are increasingly geographically dispersed due to corporate partnering, acquisitions, globalization, and related factors. While there is motivation for people to work together more closely and more effectively due to competitive pressures, the increasing geographical dispersion of talent in the workforce creates a dilemma which is not easily resolved.[2]

This article focuses on a very specific type of distant interactions with high societal value -- the production of new, patentable inventions through the work of widely displaced co-inventors. Where patentable inventions are produced by two or more parties working in concert, these individuals are deemed "joint inventors" under United States

---

a group of 11 co-inventors. *See id.*

2 United States Patent No. 7469384, "Method and System for Creating a Virtual Team Environment" (December 23, 2008).

patent laws.[3] Joint inventors hold and exercise patent rights as co-owners.[4]

Interactions between researchers resulting in joint inventions are highly demanding as they must overcome both administrative and technological hurdles imposed by United States patent laws. Administratively, interactions aimed at joint inventions must overcome communication and coordination barriers to apply and combine the collective expertise of group members. Patent laws require this type of communication between experts and combination of expertise before an invention emanating from a group process can be recognized as a joint invention for patent law purposes.[5]

The technological hurdles imposed on joint invention efforts by patent laws are even more demanding. In order to qualify for United States patents, advances of workgroups must describe complete and reproducible designs[6] that are not only new,[7] but that also constitute substantial advances over prior knowledge in their engineering fields. This test is only met if the advances are so unusual that they would not have been easily developed and obvious to average practitioners in the relevant engineering fields who were aware of all available design knowledge in the fields.[8]

Since these technological tests are demanding and eliminate most routine

---

3 *See* 35 U.S.C. § 116.

4 *See* text at notes 40-46, *infra.*

5 *See* text at notes 30-32, *infra.*

6 35 U.S.C. § 112.

7 35 U.S.C. § 102(a).

8 35 U.S.C. § 103.

innovations from qualifying for patents, issued patents record the successful results of a particularly valuable set of innovative efforts. They record the successes of technological innovators working on outlier projects at the frontiers of their fields and not the more pedestrian advances of designers working within the routine design constructs and methods employed by most engineers in the same fields.

This article uses patent records to explore two features of the workgroups and working relationships that produce patentable inventions. First, patent records for 1976 and 2006 are used to assess changes in workgroup sizes over a span of years encompassing the rise of the Internet and other electronic communication improvements. Second, the impact of the Internet other resource enhancements in recent decades in expanding successful joint invention at a distance is studied by examining the physical separation of joint inventors in 1976 and 2006. Overall, these studies are aimed at better understanding how multiple individuals interact to produce useful and patentable advances of the highest societal importance, with emphasis on the potential of new communication resources such as the Internet to increase the global range of effective invention workgroups.

I. Legal Requirements for Joint Inventions of Patentable Advances

United States patent laws regarding joint inventors build on two key sources: the basic legal standards describing the degree of knowledge required for inventorship (as developed primarily through cases involving individual inventors)[9] and the additional legal principles for determining when two or more persons have contributed sufficiently to a single invention to be deemed joint inventors and share in the ownership of the

[9] *See, e.g., Burroughs Wellcome Co. v. Barr Laboratories, Inc.*, 40 F.3d 1223 (Fed.Cir. 1994)..

resulting patent.[10]

Patent laws require that an inventor or inventors possess a particular degree of knowledge about a new and useful design to recognize the design as a possibly patentable invention. The knowledge needed for a patent is the same regardless of whether the design is produced by one party or multiple parties. It is important to understand this generally required degree of knowledge before further assessing how efforts to acquire this knowledge may be split among and jointly pursued by multiple inventors. Hence, the required knowledge of a patentable invention is summarized in subsection A in connection with the relatively simple case of a single-party invention. Subsection B extends this discussion to include the more complex situation of an invention produced through the joint efforts of multiple inventors.

A. Knowledge Constituting an Invention: The Simple Case of Work by a Single Inventor

Even in the relatively simple context of work by a single inventor, measuring sufficient knowledge of a practical advance to constitute a patentable invention has been a difficult task for courts for many years. Judicial analyses have described completed inventions as involving knowledge gained at two steps -- conception and reduction to practice.

1. Knowledge Constituting Conception of an Invention

Conception of a patentable invention involves the assembly of a mental concept or image of the advance.[11] This entails "the formation in the mind of the inventor, of a

---

[10] *See, e.g., Ethicon, Inc. v. United States Surgical Corp.*, 135 F.3d 1456 (Fed. Cir. 1998), *cert. denied*, 525 U.S. 923 (1998).

[11] *Sewall v. Walters*, 21 F.3d 411, 415, 30 USPQ2d 1356, 1359 (Fed.Cir. 1994).

definite and permanent idea of the complete and operative invention, as it is hereafter to be applied in practice."[12] A conception must include knowledge of every feature of an invention for which protection is sought in a later patent (commonly called the "claimed invention").[13] What is not required at the conception stage is knowledge that a given design will work or knowledge of the practical details that are needed to make it work.[14] This further knowledge about the workability of a design is added through additional analyses and findings in the course of reducing a new design to practice as described below.

Determining when a party has sufficient knowledge of an advance to constitute an invention conception is sometimes difficult. There is typically no bright line point at which accumulating knowledge held by an innovator reaches a sufficient level to constitute the conception of an invention, in part because it is often unclear if further design and implementation steps are needed to produce a complete design that only need commonly understood implementation steps to be successful. For purposes of patent law, a "[c]onception is complete ... when the idea is so clearly defined in the inventor's mind that only ordinary skill would be necessary to reduce the invention to practice, without extensive research or experimentation."[15] An idea is sufficiently definite and permanent to reflect a patentable invention "when the inventor has a specific, settled idea, a

---

[12] *Hybritech Inc. v. Monoclonal Antibodies, Inc.*, 802 F.2d 1367, 1376, 231 USPQ 81, 87 (Fed.Cir.1986) (citation omitted).

[13] *Coleman v. Dines*, 754 F.2d 353, 359, 224 USPQ 857, 862 (Fed.Cir. 1985).

[14] *Applegate v. Scherer*, 332 F.2d 571, 573, 141 USPQ 796, 799 (CCPA 1964).

[15] *Burroughs Wellcome Co. v. Barr Laboratories, Inc.*, 40 F.3d 1223 (Fed.Cir. 1994); *see also Sewall v. Walters*, 21 F.3d 411, 415, 30 USPQ2d 1356, 1359 (Fed.Cir. 1994).

particular solution to the problem at hand, not just a general goal or research plan he hopes to pursue."[16]

2. Importance of Corroborating Evidence

Because a conception is a mental act that is easily misrembered or falsely described in retrospect when it has significance in a patent dispute, courts have required corroborating evidence to establish the timing and scope of an invention conception. Typically, the necessary corroborating evidence is a contemporaneous disclosure that contains sufficient information and details to enable one skilled in the art to make an invention.[17] Such a disclosure confirms both the formulation of a new design and the completeness of that design. The confirmation of an invention and its completeness are closely intertwined as noted by the Federal Circuit court:

> The conception analysis necessarily turns on the inventor's ability to describe his invention with particularity. Until he can do so, he cannot prove possession of the complete mental picture of the invention. These rules ensure that patent rights attach only when an idea is so far developed that the inventor can point to a definite, particular invention.[18]

3. Knowledge Added Through a Reduction to Practice

A reduction to practice involves the first physical realization of an invention, as

---

16 *Id. See also Fiers v. Revel*, 984 F.2d 1164, 1169, 25 USPQ2d 1601, 1605 (Fed.Cir. 1993); *Amgen, Inc. v. Chugai Pharmaceutical Co.*, 927 F.2d 1200, 1206, 18 USPQ2d 1016, 1021 (Fed.Cir. 1991)(no conception of chemical compound based solely on its biological activity).

17 *Coleman v. Dines*, 754 F.2d 353, 359, 224 USPQ 857, 862 (Fed.Cir. 1985).

18 *Burroughs Wellcome Co. v. Barr Laboratories, Inc.*, 40 F.3d 1223 (Fed.Cir. 1994).

shown by producing a working example of an item or by successfully completing the steps of an innovative procedure.[19] Conception and reduction to practice may occur simultaneously or in any order. Typically, a conception precedes a reduction to practice that is guided by the conception. The workable example of the invention when reduced to practice confirms the sufficiency and completeness of the earlier design conception. However, the reverse order is possible where a useful design is implemented by accident (thereby reducing it to practice) and only later analyzed and completely understood to complete the conception of the advance.

A reduction to practice and conception may occur simultaneously where some aspect of an invention is not clear or adequately understood so as to permit replication until a working version of the invention is made in a reduction to practice. Thus, there is no conception "where results at each step do not follow as anticipated, but are achieved empirically by what amounts to trial and error."[20] Conception is not present in these sorts of instances until predictable, repeatable results are produced through a reduction to practice achieved by trial and error. No prior conception is present because, until that point, the invention is incomplete for lack of knowledge needed to describe a successful version of the invention and transfer the invention in a workable form to others.

4. Why Invention Determinations Matter for Workgroup Innovations

When and by whom an invention is made are important considerations in several patent law contexts. For example, the date when an advance occured may be important if two competing inventors or invention teams assert that they have independently

---

[19] *See id.*

[20] *Alpert v. Slatin*, 305 F.2d 891, 894, 134 USPQ 296, 299 (CCPA 1962).

developed an advance. The first inventor or group will generally be entitled to seek a patent under United States law upon the filing of a proper patent application.[21] The second inventor or group will generally be unable to take a valid patent interest and may later need to give up use of the patented invention once a patent issues to the other party. This type of controversy over invention ordering or "priority", while important in some patent contests, is not materially different in workgroup contexts than in sole inventor processes and will not be addressed in this article.

Another setting where ascertaining the knowledge comprising an invention is important is where the identity of the party or parties making an invention is in dispute. For example, an invention emerging from a workgroup may lead to a dispute over who within the workgroup was an inventor or joint inventor of the advance. Only a true inventor or group of inventors may obtain a patent for an advance.[22] This patent law rule protects against problems of over- and under-inclusion of inventors within the group of parties who can exercise patent rights and thereby limit the making, using, or selling of a patented invention.[23] Leading patent commentator Donald Chisum describes the rationales behind disallowing patent interests for non-inventors as follows:

it would be morally offensive to allow one to harvest what another has sown. The

---

[21] In most instances, United States law provides that the first party or group to invent an advance is the only party or group that can qualify for patent rights (all others are barred from such rights). *See* 35 U.S.C. § 103(f).

[22] *See*, *e.g.*, *University of Colorado Foundation Inc. v. American Cyanamid Co.*, 105 F. Supp.2d 1164, 1175, 55 USPQ2d 1909, 1918 (D. Colo. 2000); *Agawam Co. v. Jordan*, 74 U.S. 583, 602 (1869).

[23] The failure to include an inventor on a patent is referred to as nonjoinder (failure to name a joint inventor), while the failure to correctly state the inventor group is called misjoinder (erroneously naming a joint inventor).

requirement bars a patent even if the true inventor does not complain or if the true inventor is not known, as, for example, when a person discovers and imports for the first time into the United States a device in common use in a foreign country. The originality requirement limits patent monopolies to those who actually expend inventive effort successfully. It also reinforces other substantive requirements of patentability. The true originator of a new invention is an important source of information as to whether the invention in question has been in public use or disclosed in a printed publication.[24]

B. Inventions in Workgroups: Additional Standards for Joint Inventions

1. Basic Features

Inventions involving significant design contributions of two or more individuals are "joint inventions" for purposes of United States patent laws. Joint inventorship requires not only that the functional components of a patentable design stem from multiple parties, but also that the parties have worked together in a single design project to produce the resulting combined work (as opposed, for instance, to producing two isolated subcomponents independently through sequential efforts). As described by one court:

> A joint invention is the product of collaboration of the inventive endeavors of two or more persons working toward the same end and producing an invention by their aggregate efforts. To constitute a joint invention, it is necessary that each of the inventors work on the same subject matter and make some contribution to the inventive thought and to the final result. Each needs to perform but a part of the

[24] Donald Chisum, Chisum on Patents § 2.01 (2008).

> task if an invention emerges from all of the steps taken together. It is not necessary that the entire inventive concept should occur to each of the joint inventors, or that the two should physically work on the project together. One may take a step at one time, the other an approach at different times. One may do more of the experimental work while the other makes suggestions from time to time. The fact that each of the inventors plays a different role and that the contribution of one may not be as great as that of another, does not detract from the fact that the invention is joint, if each makes some original contribution, though partial, to the final solution of the problem.[25]

Current inventive processes in corporations and other organizations frequently rely on contributions by multiple innovators, but under conditions where the sources, scope, and functional importance of the contributions may be unclear:

> Most employee inventions which occur in corporate R & D departments are usually the result of the collaborative efforts of several persons, rather than one individual. Ideas leading to useful inventions often are the result of "brainstorming" sessions [in which it] is sometimes difficult to determine ... who contributed to the particular invention. Sometimes, one person will partially conceive what the invention should be. It is only later that someone else, through additional development work, fills in the remaining pieces to make the complete invention. Employee inventions in the corporate environment are generally team efforts.[26]

---

[25] *Monsanto Co. v. Kamp*, 269 F. Supp. 818, 824 (D. D.C. 1967).

[26] Richard C. Witte & Eric W. Guttag, *Employee Inventions*, 71 J.Pat. & Trademark Off. Soc'y 467, 476 (1989).

2. Collaborations Needed to Produce Joint Inventions

The requirement that joint inventors be significant collaborators on a single project adds difficulty to joint inventorship determinations. The respective contributions to an invention design of multiple persons working on the development of a new innovation must be scrutinized to determine if each party contributed a sufficient portion of an invention in a manner that makes them a joint inventor.

Examples involving two individuals will illustrate the complexity of these joint inventorship determinations. Even where two individuals contribute to the completion of a invention design, the two may or may not both be inventors. Where each has contributed materially to the specification of one or more physical subcomponents or process steps within an invention, both are probably joint inventors. However, where one individual is working at the direction of another, the person following instructions is not a joint inventor, even if the work of that second party relates to a key feature of an invention. Similarly, if one person works to perfect or test an already completed invention design, the party contributing in this way is not a joint inventor.

Some joint work by each party in developing a new design is needed to make parties joint inventors. If a person develops the design for a product component and a second person incorporates the first design in a further product designed in a separate project, the two designers are not co-inventors. Thus, for example, in *Burroughs Wellcome Co. v. Barr Laboratories, Inc.*,[27] the Federal Circuit court considered and rejected an argument that groups that worked at different times on similar chemical

---

[27] 40 F.3d 1223 (Fed.Cir. 1994).

projects were co-inventors as to some of the later chemical discoveries. The court later commented on its analysis in *Burroughs Wellcome* as follows:

> If [the later inventors] had conceived the structures of the claimed compounds, but were then unable to make them without [the prior inventor's] help, [the prior inventor] might have been a coinventor. That is not this case, however. Here, there is no evidence in the record that [the prior inventor] knew that [the later inventors] were attempting to make any of the claimed compounds, or even that [the later inventors] had any contact at all with [the prior inventor] after the claimed compounds were conceived. [The prior inventor] neither made the claimed compounds nor attempted to make them, and he did not have "'a firm and definite idea' of the claimed combination as a whole." Although [one of the later inventors] may have learned the beta-lactam method from [the prior inventor], teaching skills or general methods that somehow facilitate a later invention, without more, does not render one a coinventor.[28]

Congress confirmed, however, that parties working at different times and in different locations can sometimes be co-inventors if they are working on a shared design project. The Patent Act recognizes that these parties can still be joint inventors by specifying that "[i]nventors may apply for a patent jointly even though (1) they did not physically work together or at the same time, (2) each did not make the same type or amount of contribution, or (3) each did not make a contribution to the subject matter of every claim of the patent."[29] Hence, distantly separated workgroups of the type studied

---

[28] *Board of Education ex rel. Florida State University v. American Bioscience, Inc.*, 333 F.3d 1330, 1341-42 (Fed.Cir. 2003).

[29] 35 U.S.C. § 116.

in this article, perhaps working very far apart and at different times of the day, were among the sorts of potential joint inventors contemplated by Congress in its provisions specifying that joint inventors can produce a patentable invention and qualify to share patent ownership as joint inventors while not physically working together or at the same time.

3. The Importance of Communication Between Joint Inventors

Careful communication between parties working on joint innovation projects is typically needed for the parties to be joint inventors. The need for extensive communication between joint inventors -- and the corresponding communications challenges associated with workgroups involving large distances between group members precluding face to face interactions -- was by Professor William Robinson as early as 1890 in his treatise on patent law:

> Where two or more persons acting jointly, conceive the same idea of means, they are joint inventors and are jointly entitled to the patent. The sphere of their joint labors and success is thus the mental part of the inventive act. That one conceives the idea and another reduces it to practice; that one conceives the principal idea and the other an idea which is ancillary to and inseparable from it; that one conceives one idea and the other a different idea, both of which are united in the concrete invention, -- neither of these are joint invention, nor do they give to the inventors the right to become joint patentees. Only where the same single, unitary idea of means is the product of two or more minds, working *pari passu*, and in communication with each other, is the conception truly joint and the result a joint

invention.[30]

Another commentator, assessing the minimum interactions needed to make two parties co-inventors, recognized that communication between the parties is a necessary precursor to the types of interactions that will make them joint inventors:

> Separate ideas can only be linked in a joint invention if at least one of the inventors, while conceiving or perfecting his ideas, considers the other inventor's ideas. Thus, the minimum required collaboration is some form of communication between two joint inventors. This can occur if the inventors work serially, one building on the prior work of the other, or in parallel, the two working separately and then meshing their separate works into one.[31]

The significance of communication in defining the minimum circumstances enabling the types of interactions leading to joint inventorship suggest that changes in communication technologies -- such as the advent of the Internet -- should expand the range of potentially successful interactions leading to patentable inventions.[32] The empirical studies conducted as part of this research examine whether this type of communication resource improvement seems to have increased the number and size of innovation workgroups.

4. Falling Short: Collaborations and Contributions Not Constituting

---

30 1 W. Robinson, The Law of Patents for Useful Inventions § 396 (1890).

31 W. Fritz Fasse, *The Muddy Metaphysics of Joint Inventorship: Cleaning Up After the 1984 Amendments to 35 U.S.C. § 116*, 5 Harv. J.L. & Tech. 153, 172 (1992).

32 *But see* John C. Gooch, *A Study of Collaborative Discourse Among Disciplinary Experts,* Society for Technical Communication Proceedings, http://www.stc.org/confproceed/2001/PDFs/STC48-000167.PDF (noting that "experts as members of organizations, tend to rely on an organization's established mechanisms for communication").

Joint Invention Processes

A number of judicial analyses have identified specific types of contributions to group efforts that have not made the parties joint inventors.[33] Courts have held that a party does not become a joint inventor by:

1) suggesting a desired end or result, with no suggestion of means;[34]

2) following the instructions of the person or persons who conceive the solution;[35]

3) acting to reduce to practice an already completely conceived invention;[36]

---

[33] *See generally* Donald Chisum, Chisum on Patents § 2.02 (2008).

[34] *Ethicon, Inc. v. United States Surgical Corp.*, 937 F. Supp. 1015, 1035 (D. Conn. 1996) , *aff'd*, 135 F.3d 1456 (Fed. Cir. 1998), *cert. denied*, 525 U.S. 923 (1998) ("An entrepreneur's request to another to create a product that will fulfill a certain function is not conception -- even if the entrepreneur supplies continuous input on the acceptability of offered products."); *University of California v. Synbiotics Corp.*, 29 USPQ2d 1463 (S.D. Calif. 1993); *S.C. Johnson & Son, Inc. v. Carter-Wallace, Inc.*, 225 USPQ 1022, 1038 (S.D.N.Y. 1985), *aff'd in part, vacated in part, and remanded*, 781 F.2d 198 (Fed. Cir. 1986) ("Suggestions by others that do not reveal the entire invention and how to achieve it do not negate invention by the one who carries the project forward to its successful conclusion.").

[35] *Mineral Separation, Ltd. v. Hyde*, 242 U.S. 261, 270 (1916)("The claim that the patentees of the patent in suit are not the original discoverers of the process patented because an employee of theirs happened to make the analyses and observations which resulted immediately in the discovery cannot be allowed. The record shows very clearly that the patentees planned the experiments in progress when the discovery was made; that they directed the investigations day by day, conducting them in large part personally, and that they interpreted the results"); *Eli Lilly & Co. v. Aradigm Corp.*, 376 F.3d 1352 (Fed.Cir. 2004); *Trovan, Ltd. v. Sokymat SA*, 299 F.3d 1292, (Fed.Cir. 2002); *Fina Oil & Chemical Co. v. Ewen*, 123 F.3d 1466, 1473 (Fed.Cir. 1997).

[36] *Chirichillo v. Prasser*, 30 F. Supp. 2d 1132, 1136 (E.D.Wis. 1998) ("One does not qualify as a joint inventor by merely assisting the actual inventor after conception of the claimed invention. ... One of ordinary skill in the art who simply reduced the inventor's idea to practice is not necessarily a joint inventor."); *Maxwell v. K Mart Corp.*, 880 F. Supp. 1323, 1334 (D.Minn. 1995) ("A joint invention is the product of collaboration of the inventive endeavors of two or more persons

4) providing information on design elements with no knowledge of the ultimate design project;[37]

5) completion of steps to prove that an invention is useful, even if the steps are important to subsequent use or commercial exploitation of the patented invention;[38]

6) ongoing collaboration or interaction regarding similar projects where there is no evidence of a joint contribution to the particular design effort leading to a patented invention;[39]

5.. Consequences of Joint Invention

One key consequence of joint inventorship under present patent laws is that joint inventors should apply for patents together. The Patent Act states that "[w]hen an invention is made by two or more persons jointly, they shall apply for [a] patent jointly."[40] As a corollary, a patent applied for and obtained by a party who is not an

---

working toward the same end and producing an invention by their aggregate efforts. ... To be a joint inventor, one must make some original contribution to the inventive thought and the final solution of the problem. ... One does not become a joint inventor, however, merely by assisting the actual inventor after the inventive concept is conceived.").

37 *Ethicon, Inc. v. U.S. Surgical Corp.*, 135 F.3d 1456, 1460 (Fed.Cir. 1998)("One who simply provides the inventor with well-known principles or explains the state of the art without ever having `a firm and definite idea of the claimed combination as a whole does not qualify as a joint inventor.").

38 *See Burroughs Wellcome Co. v. Barr Labs., Inc*, 40 F.3d 1223, 1230 (Fed.Cir. 1994).

39 *See Trovan, Ltd. v. Sokymat SA*, 299 F.3d 1292, 1303-04 (Fed.Cir. 2002).

40 35 U.S.C. § 116.

inventor of the invention claimed is invalid.[41] However, in cases where the wrong parties apply for a patent and a patent issues in which the true inventors are misstated, the patent may sometimes be corrected, thereby saving its validity.[42] The court in *Pannu v. Iolab Corp.*[43] described the following procedures for correcting patents that incorrectly identify inventors:

> When a party asserts invalidity under Section 102(f) due to nonjoinder [of an actual inventor among the parties listed as the inventors in a patent], a district court should first determine whether there exists clear and convincing proof that the alleged unnamed inventor was in fact a co-inventor. Upon such a finding of incorrect inventorship, a patentee may invoke section 256 to save the patent from invalidity. Accordingly, the patentee must then be given an opportunity to correct inventorship pursuant to that section. Nonjoinder may be corrected "on notice and hearing of all parties concerned" and upon a showing that the error occurred without any deceptive intent on the part of the un-named inventor. ... 35 U.S.C. Section 256; *see Stark v. Advanced Magnetics, Inc.*, 119 F.3d 1551, 1555, 43 USPQ2d 1321, 1324 (Fed. Cir. 1997) ('[T]he section allows addition of an unnamed actual inventor, but this error of nonjoinder cannot betray any deceptive intent by that inventor.')[44]

Even if an initially misstated list of inventors is corrected in this manner, the

---

41 *See* 35 U.S.C. § 102(f).

42 *See* 35 U.S.C. § 256; Donald Chisum, Chisum on Patents § 2.03 (2008).

43 155 F.3d 1344 (Fed.Cir. 1998).

44 *Id.* at 1350-51.

patent at stake may still be invalid for reasons related to the initial misstatement of inventorship. For example, in *Pannu*, the accused infringer asserted that the patent at issue was still invalid even if a previously omitted coinventor was added to the patent under the procedure discussed above because the patent failed to disclose information about the best mode for practicing the claimed invention that was known to the omitted inventor but not the initially stated inventor.[45] Thus, in this and other respects, the knowledge and previous work of the actual set of inventors may invalidate a patent, even if the set of inventors is belatedly corrected.[46]

II. Changes in Group Innovation: Evidence from the Patent Record

Several types of changes in recent years in supporting resources and research techniques may have produced corresponding alterations in innovative workgroups and associated research processes. In particular, changes in communication resources such as the advent of the Internet seem likely to have enabled members of workgroups to have communicated more effectively and over greater distances. In addition, the increasingly complex nature of research in many fields may have necessitated greater use of workgroups -- as opposed to solo inventors -- in order to carry on effective research programs based on the combined expertise of team members and produce patentable inventions.

---

45 *Id.* at 1347-50.

46 For example, if A and B worked jointly on an advance and B secretly commercialized the invention for two years, under U.S. patent law whether or not B was a coinventor might determine if the patent was valid. Secret commercialization of an advance by an inventor for more than one year before applying for a patent will invalidate the resulting patent, while secret commercialization by someone who is not an inventor will have no effect on the validity of the patent. 35 U.S.C. § 102(b).

This study focused on innovation groups producing patentable inventions for which patents issued in 1976 and 2006, a gap in time chosen to ensure that the groups studied operated before and after the widespread usage of the Internet and other new electronic communication resources. It was hypothesized that:

1) The prevalence of inventive groups as sources of patentable inventions would increase significantly with the advent of the Internet;

2) The prevalence of large innovative groups would increase most substantially due to the addition of the Internet in technological fields where large group innovation was already recognized as advantageous and relatively common prior to the implementation of the Internet; and

3) The prevalence of workgroups with widely separated innovators would increase with the implementation of the Internet.

Evidence from patent records seems to bear out each of these hypotheses as described in the remainder of this section.

A. Frequency of Inventive Groups Across All Technology Types

One lesson from the patent record is that innovation -- at least through projects producing patentable advances -- is now primarily a group process. In order to assess the importance of innovative groups in producing patentable inventions, I evaluated bibliographic data from patents to determine the number of inventors associated with each utility patent issued in 1976 and in 2006, the average number of inventors associated with each patent in these years, and the frequency distribution of different invention group sizes.

1. Inventor Groups in 1976

Inventor groups only accounted for a minority of inventions in 1976. Almost 60 percent of all patented inventions were made by a single inventor. Individuals acting alone were the norm among inventors in this period. Where inventions were the work of two or more parties, the size of invention workgroups was small. The average inventor group size for patents issued in 1976 was 1.67, while the median was 1. The standard deviation of the inventor group size distribution was 0.999. The frequency distribution of inventor group sizes was as follows:

Table 1

Invention Numbers by Group Size 1976

Number of Inventors	Frequency	Percent	Cumulative Percent
1	40998	58.4	58.4
2	17622	25.1	83.4
3	7456	10.6	94.1
4	2622	3.7	97.8
5	995	1.4	99.2
6	457	0.7	99.9
7	99	0.1	100
Total	70249	100	

One surprising feature of these 1976 results was the small number of inventive groups of any substantial size. Inventive groups involving four or more persons produced only about six percent of all inventions. This suggests that, in this period, the potential benefits of adding workgroup members and achieving greater inventive effectiveness or efficiency did not seem to be worth the incremental communication or coordination burdens of operating larger invention groups.

2. Inventor Groups in 2006

Inventor groups were much more prevalent in 2006 than in 1976 as shown in Table 2. Only 35.8 percent of all patents issued in 2006 involved inventions by one individual. The remainder – a remarkable 64.2 percent of all patents issued in 2006 – involved two or more inventors. This means that the problems of intra-inventor communication within inventive groups were burdens on most of the innovation processes leading to patented inventions in 2006.

The average size of inventive groups seems to have grown considerably since 1976. The average number of inventors associated with each patent issued in 2006 was 2.46, almost a 50 percent increase over the average of 1.67 in 1976. The median number of inventors per patent was 2.00 in 2006, double the median in 1976. More than 20 percent of patents issued in 2006 involved four or more inventors, in contrast to only 6 percent of patents in 1976.

The distribution of the inventor group sizes around the average value of 2.46 in 2006 had a standard deviation of 1.616, with the increase over the comparable standard deviation for 1976 of 0.999. The larger figure for 2006 reflects the greater range of variations in workgroup sizes in 2006. Table 2 summarizes the distribution of workgroup sizes for 2006:

Table 2

Invention Numbers by Group Size 2006

Number of Inventors	**Frequency**	**Percent**	**Cumulative Percent**
-	-	-	-
1	62385	35.8	35.8
2	44696	25.6	61.4
3	30206	17.3	78.7
4	17244	9.9	88.6
5	9287	5.3	93.9
6	4843	2.8	96.7
7	3640	2.1	98.8
8	2024	1.2	99.9
9	138	0.1	100
Total	174463	100	

The greater prevalence of large invention groups having four members or more suggests that such larger groups were seen as having value by 2006. At least two different explanations may account for this. First, the mix of types of inventions in 2006 may have shifted such that more invention efforts leading to patents were undertaken in fields where the inputs of numerous contributors was necessary (or at least highly advantageous) in producing inventions and patents. Second, improvements in communication and inventor coordination methods may have decreased the burdens of operating these larger groups across all technology categories, resulting in an increase in larger inventive groups in diverse technology areas. Subsequent studies of changes in group size for particular technology classes were undertaken to explore these possible explanations, as described in subsection B below.

3. Measuring the Importance of Large Innovation Groups

While there were more inventive groups at work in 2006 than in 1976 -- at least in the types of projects successfully leading to patentable inventions -- there were also more patents issued in 2006 than in 1976. To eliminate the effects of overall growth in patent numbers, it is important to focus on the factional prevalence of groups of different sizes in these two years rather than the number of innovative groups producing patentable inventions. This focus will normalize the frequency counts reported above -- that is, recast them as if we were dealing with "normal" or similar sized patent counts in the two years. This type of normalization can easily be achieved by computing the percentages of patents falling into various inventor group size categories. The percentage figures effectively treat the patent systems in these two years as if they were of equal size and then characterize the fractional breakdown of inventor group size counts for the patents issued in these two years.

Focusing on percentage figures rather than group counts produces the following:

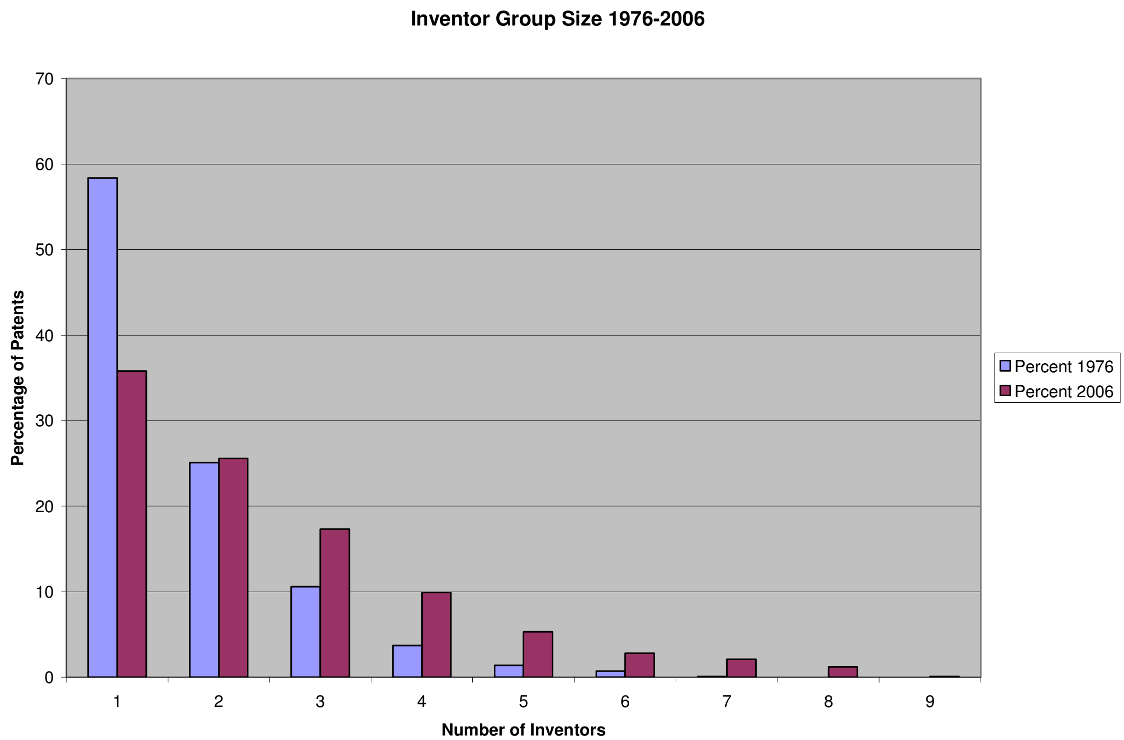
Table 3

Group Size Comparison

Inventors	Percent 1976	Percent 2006
1	58.4	35.8
2	25.1	25.6
3	10.6	17.3
4	3.7	9.9
5	1.4	5.3
6	0.7	2.8
7	0.1	2.1
8	0	1.2
9	0	0.1

This corresponds to the following histogram:

Figure 1



A comparison of the percentage figures in Table 3 with a Chi-square test showed that there was a statistically significant difference in the distribution of inventor group sizes in 1976 and 2006 even after accounting for differences in numbers of patents in these years. The Chi-square statistic for the difference between these percentages equals 222.741 with 8 degrees of freedom. The two-tailed p value is less than 0.0001.

The findings summarized in tables 1, 2 and 3 support the hypothesis that the prevalence of inventive groups would increase with the advent of the Internet. Not only did the number of workgroups increase substantially, but the prevalence of larger size groups increased as well. This evidence is indicates that workgroup innovations – particularly those involving four or more innovators – were much more common in 2006 than in 1976.

B. Inventor Group Size Differences Across Technology Types

In both 1976 and 2006, the average inventor group size varied greatly across different types of technologies. The technology categories used in this study are primary technology categories as defined by the United States Patent and Trademark Office (USPTO) and used to characterize the primary technological field of each issued patent.[47] This portion of the present study looked at the distribution of workgroup sizes for the 20 technology categories with the largest numbers of patents in 2006.[48] The average inventor group sizes and distributions for these 20 technology categories were analyzed for both 2006 and 1976.

1. Inventor Groups in 1976by Technology Type

Table 4 summarizes the 1976 inventor group size data for different technology categories. A figure for the overall average inventor group size for all patents in 1976 is included in this table at the position it would fall in the ordering of inventor group sizes

---

[47] The USPTO uses patent classes as the primary divisions of technology within the United States Patent Classification System. The Patent Classification System utilizes codes that reflect both a primary class and subclass for an invention. Classification codes in patent records are typically expressed as "482/1". The first number, 482, represents the class of invention. The number following the slash is the subclass of invention within the class. The USPTO uses about 450 classes of invention and about 150,000 subclasses of invention in the Patent Classification System. *See* United States Patent and Trademark Office, Classification Help File (2008), http://www.uspto.gov/go/classification/help.htm.

[48] Both technology class 424 and 514 relate to "Drug, Bio-Affecting and Body Treating Compositions." The USPTO considers class 514 to be an integral part of class 424. Both cover drugs, but the chemical compositions of the drugs that fall in each differ. *See* United States Patent and Trademark Office, Schedule Class 514 Drug, Bio-Affecting and Body Treating Compositions, http://www.uspto.gov/go/classification/uspc514/sched514.htm.

(which is at the middle of the 20 technologies). The technology codes reflect the author's rough regroupings of the PTO's technology codes into four loosely related fields.

Table 4

Inventor Group Size by Technology Category 1976

Technology Category	**USPTO Category Number**	**Technology Code**	**Rank in 1976**	**Average Inventors in 1976**	**Numbers of Patents 1976**
Chemistry: molecular biology and microbiology	435	C/B	1	2.32	375
Drug, bio-affecting and body treating compositions	514	C/B	2	2.26	1264
Drug, bio-affecting and body treating compositions	424	C/B	3	2.06	411
Image analysis	382	S	4	1.95	80
Semiconductor device manufacturing: process	438	CH	5	1.91	275
Stock material or miscellaneous articles	428	C/B	6	1.84	922
Multiplex communications	370	S	7	1.84	135
Active solid-state devices (e.g., transistors, solid-state diodes)	257	CH	8	1.82	336
Static information storage and retrieval	365	S	9	1.73	218
Radiant energy	250	M	10	1.68	641
Average for All Patents	NA	NA	NA	1.67	70249
Computer graphics processing and selective visual display systems	345	S	11	1.66	152
Telecommunications	455	S	12	1.60	231
Electricity: measuring and testing	324	M	13	1.59	471
Optical: systems and elements	359	M	14	1.56	419
Pulse or digital communications	375	S	15	1.56	130
Optical waveguides	385	M	16	1.55	91
Measuring and testing	73	M	17	1.55	1086
Communications: electrical	340	M	18	1.52	487
Electrical connectors	439	M	19	1.43	458
Electrical computers and digital processing systems: multicomputer data transferring	709	S	NA	2.75	4

Technology Code Key:
C/B = Chemistry and Biology
CH = Computer Hardware
S = Software and Information Processing
M = Mechanical

The last USPTO technology category in this listing (709 -- Electrical computers and digital processing systems: multicomputer data transferring) is not ranked for 1976 as it was not used substantially in this year (only 4 patents were recorded in this category in 1976). The same patterns in inventor group size that were noted for 2006 also prevailed in 1976. Patented advances in chemistry and biology domains were pursued by innovation groups that were substantially larger than most other types of technologies. Computer hardware advances stemmed from groups that were greater than average in size, although less so than chemistry and biology advances. Software advances were pursued by groups at or below the average size. Mechanical advances were also pursued by groups at or below the average size.

2. Inventor Groups in 2006

The results of the inventor group analyses for 2006 are presented in Table 5.

Table 5

Inventor Group Size by Technology Category 2006

Technology Category	USPTO Category Number	Technology Code	Rank in 2006	Average Inventors in 2006	Number of Patents in 2006
Drug, bio-affecting and body treating compositions	514	C/B	1	3.82	3359
Chemistry: molecular biology and microbiology	435	C/B	2	3.18	3103
Stock material or miscellaneous articles	428	C/B	3	3.06	1950
Drug, bio-affecting and body treating compositions	424	C/B	4	2.87	2140
Optical waveguides	385	M	5	2.86	1972
Semiconductor device manufacturing: process	438	CH	6	2.81	4795
Electrical computers and digital processing systems: multicomputer data transferring	709	S	7	2.68	2412
Active solid-state devices (e.g., transistors, solid-state diodes)	257	CH	8	2.66	4478
Radiant energy	250	M	9	2.55	2283
Multiplex communications	370	S	10	2.51	3806
Average for All Patents	NA	NA	NA	2.46	174463
Measuring and testing	73	M	11	2.39	1913
Electricity: measuring and testing	324	M	12	2.38	1961
Image analysis	382	S	13	2.34	2299
Optical: systems and elements	359	M	14	2.32	2365
Telecommunications	455	S	15	2.29	4064
Computer graphics processing and selective visual display systems	345	S	16	2.29	2934
Static information storage and retrieval	365	S	17	2.29	2171
Pulse or digital communications	375	S	18	2.26	2383
Communications: electrical	340	M	19	2.24	2215
Electrical connectors	439	M	20	2.05	2287

Technology Code Key:
C/B = Chemistry and Biology
CH = Computer Hardware
S = Software and Information Processing
M = Mechanical

Several patterns are apparent in this inventor group size data. First, advances in "unpredictable sciences" such as chemistry and biology seem to involve especially large inventor groups. Advances in these fields may be most effectively pursued by multiple researchers as no one person can project the implications of design choices in these fields. Given this unpredictability and inability of one inventor to project a single design vision into a complex, functional design, numerous researchers may be needed to speculate on and test possible design directions. In short, the lack of predictability in these fields may impede effective design efforts by one individual acting alone. Similar considerations may limit the effectiveness of relatively small inventor groups.

Second, computer hardware design projects also seem to involve greater than average inventor group sizes, but less extensive groups than those working in the chemistry and biology fields. Still, the size of the inventor groups was generally high, with an average of nearly three inventors per group in this field. Hence, in this area also, the need to coordinate several inventors is also an important problem in this technology area.

Third, at an opposite extreme, innovations that turn on information processing advances implemented through various types of computer software seem to involve particularly small inventor groups. Technologies of this sort all involved less than average size inventor groups. This suggests that innovation by a lone inventor or small innovation group may be more viable in software-related fields and that coordination and communication problems among innovators may be less substantial in these areas.

Finally, several types of innovation that involved mechanical engineering emerged from inventor groups with a wide variety of sizes. While these types of advances all involved physical apparatus or materials design, particular fields may have demanded inputs from different numbers of specialists, thereby leading to different inventor group size needs. Alternatively, the incomplete conceptualization of some of these fields due to their recent development (for example, optical waveguide designs) may cause them to be much like the unpredictable sciences of chemistry and biology for purposes of group formation and inventive group size. If this is the case, these developing fields may tend to need larger invention groups for the same reasons as the chemistry and biological research fields.

3. Changes in Inventor Group Size from 1976 to 2006

Table 6 presents the changes in inventor group size averages between 1976 and 2006 for the 20 technology categories studied. The average inventor group for all patents increased in size over this period from 1.67 to 2.46. Overall, invention group size patterns in 1976 and 2006 were similar. This is reflected in the fact that most of the top ranked categories in 2006 were also high ranked in 1976. The exceptions were the categories involving optical waveguides and measuring and testing technologies, which moved up substantially in the rankings, and image analysis, static information and storage technologies, and computer graphics processing and selective visual display systems, which moved down up substantially in the group size rankings between 1976 and 2006. Differences in design principles or methodologies in these fields between 1976 and 2006 may explain the changes in average inventor group sizes in later years, but these sorts of domain-specific analyses are beyond the scope of this study.

Table 6

Inventor Group Size by Technology Category 1976 to 2006

Technology Category	USPTO Category Number	Technology Code	Rank in 2006	Rank in 1976	Average Inventors in 2006	Average Inventors in 1976
Drug, bio-affecting and body treating compositions	514	C/B	1	2	3.82	2.26
Chemistry: molecular biology and microbiology	435	C/B	2	1	3.18	2.32
Stock material or miscellaneous articles	428	C/B	3	6	3.06	1.84
Drug, bio-affecting and body treating compositions	424	C/B	4	3	2.87	2.06
Optical waveguides	385	M	5	16	2.86	1.55
Semiconductor device manufacturing: process	438	CH	6	5	2.81	1.91
Electrical computers and digital processing systems: multicomputer data transferring	709	S	7	NA	2.68	2.75
Active solid-state devices (e.g., transistors, solid-state diodes)	257	CH	8	8	2.66	1.82
Radiant energy	250	M	9	10	2.55	1.68
Multiplex communications	370	S	10	7	2.51	1.84
Average All Patents	NA	NA	NA	NA	2.46	1.67
Measuring and testing	73	M	11	17	2.39	1.55
Electricity: measuring and testing	324	M	12	13	2.38	1.59
Image analysis	382	S	13	4	2.34	1.95
Optical: systems and elements	359	M	14	14	2.32	1.56
Telecommunications	455	S	15	12	2.29	1.60
Computer graphics processing and selective visual display systems	345	S	16	11	2.29	1.66
Static information storage and retrieval	365	S	17	9	2.29	1.73
Pulse or digital communications	375	S	18	15	2.26	1.56
Communications: electrical	340	M	19	18	2.24	1.52
Electrical connectors	439	M	20	19	2.05	1.43

Technology Code Key:

C/B = Chemistry and Biology
CH = Computer Hardware

S = Software and Information Processing
M = Mechanical

All of the technology groups for which substantial data were available (the 709 group did not involve a substantial number of patents in 1976 and changes in this category were ignored accordingly) showed substantial increases in average innovation group size between 1976 and 2006. This indicates that the benefits of the communication and other resource improvements over these years were probably felt in workgroups addressing all technology categories.

The similar ordering of inventor group size rankings for most of the 20 technology classes suggests that the same technology-specific advantages of group work were operative in 2006 and 1976. For most technology categories, the largest inventive groups (on average) were found in the same technology categories in 1976 and 2006. This suggests that the technology-specific advantages of larger inventive groups in 1976 carried over, for the most part, into 2006 and caused researchers in most of the 20 technologies studied to seek to increase their inventor group sizes with similar vigor in these years.

However, growth rates for inventor group sizes from 1976 to 2006 were not equal across all the technology categories under study. Table 7 shows the ratios of average inventor group sizes for 2006 relative to their averages in 1976. The technology classes are listed in descending order of their growth ratios. The amount by which a ratio exceeds 1.0 reflects the percentage increase in the average inventor group size over between these years. For example, the ratio of 1.47 for all patents indicates that the 2006 average group size was 47 percent larger than its 1976 counterpart. Many of the technology categories under study had growth ratios at or near the 1.47 growth ratio for all patents, suggesting that the growth in workgroup sizes in these technology areas was responding to forces and increased resource potentials that were available and influential across all technology types.

Table 7

Group Size Growth Rates 1976 to 2006

Technology Category	USPTO Category Number	Technology Code	Average Inventors in 2006	Average Inventors in 1976	Ratio of Averages
Optical waveguides	385	M	2.86	1.55	1.85
Drug, bio-affecting and body treating compositions	514	C/B	3.82	2.26	1.69
Stock material or miscellaneous articles	428	C/B	3.06	1.84	1.66
Measuring and testing	73	M	2.39	1.55	1.54
Radiant energy	250	M	2.55	1.68	1.52
Electricity: measuring and testing	324	M	2.39	1.55	1.50
Optical: systems and elements	359	M	2.32	1.56	1.49
Communications: electrical	340	M	2.24	1.52	1.47
Average All Patents	NA	NA	2.46	1.67	1.47
Semiconductor device manufacturing: process	438	CH	2.81	1.91	1.47
Active solid-state devices (e.g., transistors, solid-state diodes)	257	CH	2.66	1.82	1.46
Pulse or digital communications	375	S	2.26	1.56	1.45
Electrical connectors	439	M	2.05	1.43	1.43
Telecommunications	455	S	2.29	1.60	1.43
Drug, bio-affecting and body treating compositions	424	C/B	2.87	2.06	1.39
Computer graphics processing and selective visual display systems	345	S	2.29	1.66	1.38
Chemistry: molecular biology and microbiology	435	C/B	3.18	2.32	1.37
Multiplex communications	370	S	2.51	1.84	1.36
Static information storage and retrieval	365	S	2.29	1.73	1.32
Image analysis	382	S	2.34	1.95	1.20
Electrical computers and digital processing systems: multicomputer data transferring	709	S	2.68	2.75	0.97

Technology Code Key:

C/B = Chemistry and Biology
CH = Computer Hardware
S = Software and Information Processing
M = Mechanical

A few of the growth ratios pointed towards especially high or low growth in the size of workgroups in specific technology areas. Advances involving optical waveguides, drug, bio-affecting and body treating compositions, and stock material or miscellaneous articles showed group size growth rates that were substantially higher than average, suggesting that group efforts in these areas were particularly advantaged by the communications and other resource changes between 1976 and 2006. In contrast, the growth rates for inventor group sizes for groups producing advances in multiplex communications, static information storage and retrieval, and image analysis advances were particularly small relative to the average group size growth for all patents, suggesting that groups working on these sorts of advances were not as advantaged by the resource changes between 1976 and 2006 as workgroups in other types of fields.

The findings reflected in Table 7 do not support the hypothesis that fields already exhibiting a high prevalence of large innovative groups would see the most substantial increases in work group size due to the addition of the Internet and other communication technologies. The highest growth rates shown in Table 7 were found not for those technology categories with the highest average group sizes in 1976 (as indicated by the rankings for that year), but rather in technology categories in the middle to bottom of the size rankings.

The categories with the top size rankings in 1976 experienced some of the lowest growth rates, suggesting that already large groups were subject to size limits that were especially hard to overcome even though many researchers in the same field were already convinced of the value of large work groups. Hence, these fields were not as much influenced by the Internet and other communication enhancements as those technology categories with relatively small invention groups in 1976. This may reflect that, even with the communications enhancements of the Internet and other new resources implemented between 1976 and 2006, participants in relatively large innovative groups were still more impeded by communications complexity and coordination problems in adding one or more members to their groups than were their small group counterparts.

C. Distributions of Group Sizes Across Technologies

The distributions of group sizes for particular technologies also varied substantially. The standard deviation figures for technology-specific distributions of inventor group sizes indicates the variability of group sizes for these technologies. Table 8 lists the standard deviations for the 20 categories under study. The entries in this table are listed in descending order for the standard deviations in 2006, meaning from the technology category with the greatest spread or variation in invention group sizes in that year down to the least variation.

Table 8

Group Size Standard Deviations in 1976 and 2006

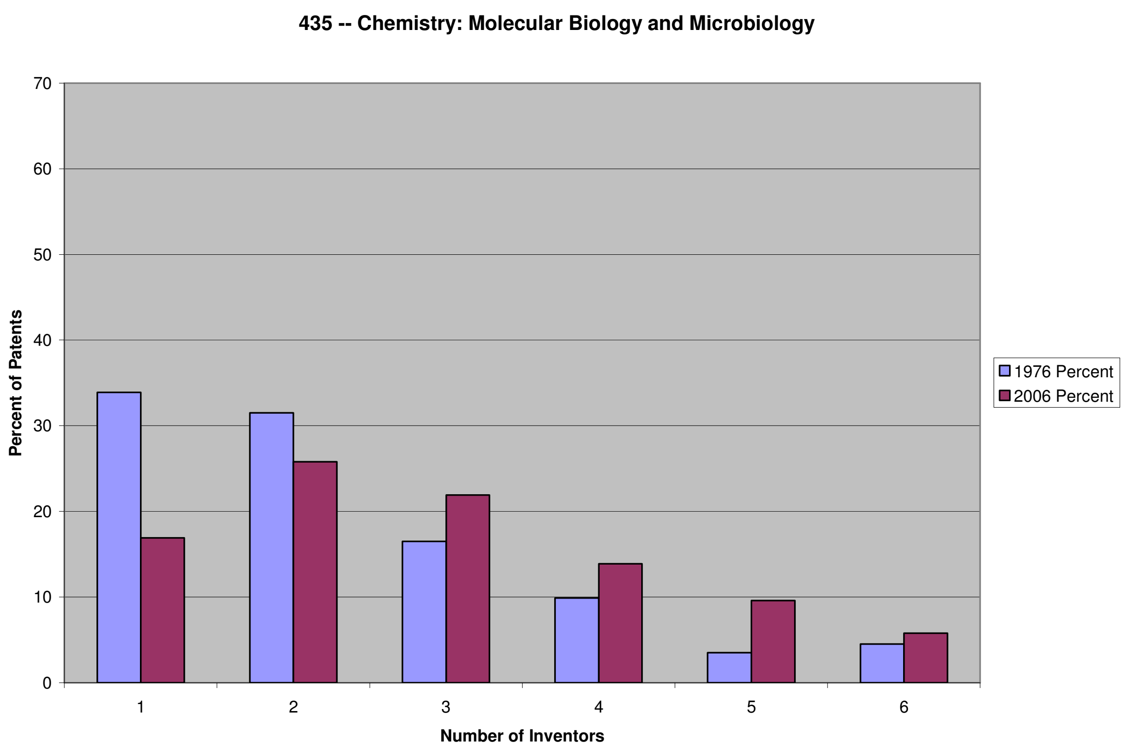
Technology Category	USPTO Category Number	Technology Code	Standard Deviation 2006	Standard Deviation 1976
Drug, bio-affecting and body treating compositions	514	C/B	2.12	1.29
Chemistry: molecular biology and microbiology	435	C/B	1.78	1.38
Stock material or miscellaneous articles	428	C/B	1.74	1.05
Semiconductor device manufacturing: process	438	CH	1.72	1.09
Optical waveguides	385	M	1.70	0.85
Active solid-state devices (e.g., transistors, solid-state diodes)	257	CH	1.69	1.00
Drug, bio-affecting and body treating compositions	424	C/B	1.68	1.19
Electrical computers and digital processing systems: multicomputer data transferring	709	S	1.64	1.50
Radiant energy	250	M	1.62	0.96
Average All Patents	NA	NA	1.62	1.00
Multiplex communications	370	S	1.55	1.04
Optical: systems and elements	359	M	1.53	0.92
Measuring and testing	73	M	1.53	0.89
Image analysis	382	S	1.52	1.32
Electricity: measuring and testing	324	M	1.50	0.87
Computer graphics processing and selective visual display systems	345	S	1.50	0.91
Telecommunications	455	S	1.49	1.01
Static information storage and retrieval	365	S	1.49	0.98
Communications: electrical	340	M	1.48	0.85
Pulse or digital communications	375	S	1.40	0.84
Electrical connectors	439	M	1.27	0.69

Technology Code Key:
C/B = Chemistry and Biology
CH = Computer Hardware
S = Software and Information Processing
M = Mechanical

The distributions for the 20 categories of technologies show markedly different patterns. The histograms for all 20 categories are reproduced in Appendix A. A few particularly interesting distributions for specific technologies are discussed here.

At least three patterns are present in the group size distributions. Some technologies -- particularly those related to biology and chemistry advances – had substantial variations in group sizes in 1976 with even broader variations in 2006. This pattern is illustrated by the following group size histogram for the USPTO primary technology category 435 covering molecular biology and microbiology advances:

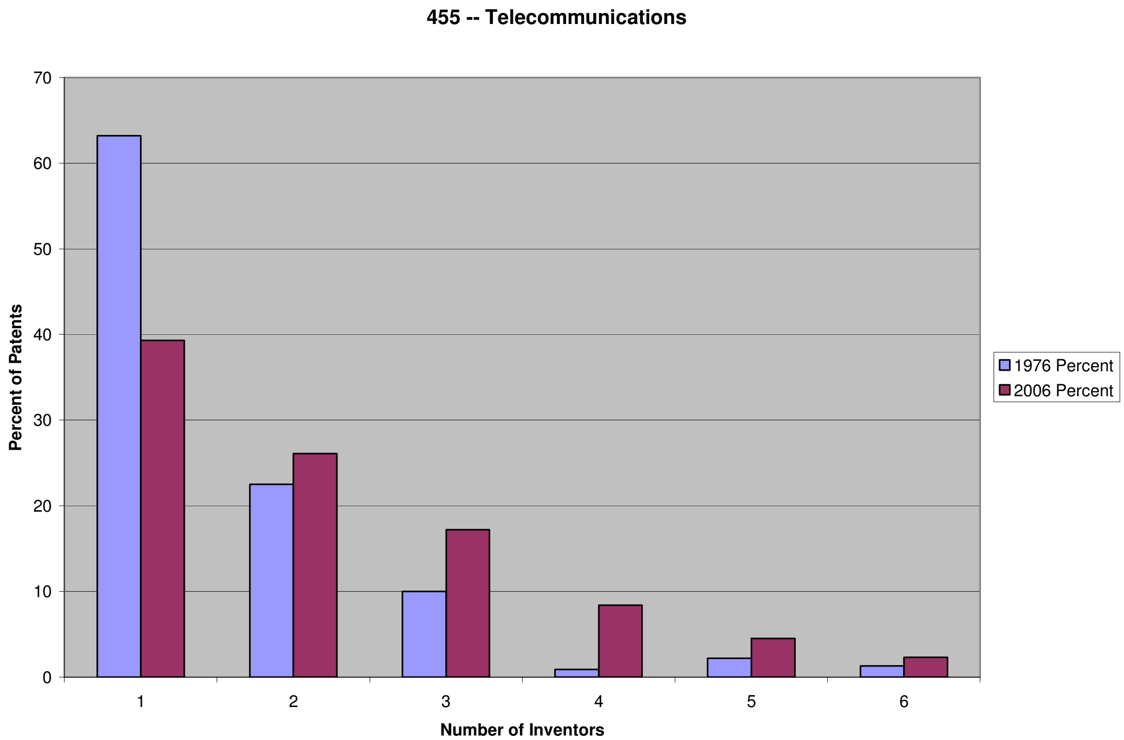
Figure 2



This distribution clearly indicates the substantial importance of inventive groups in this area as far back as 1976, but the even greater prevalence of large group efforts by 2006.

A second pattern present among several technologies -- particularly advances associated with computer hardware designs -- involved few group innovations in 1976, but a substantial shift to group advances by 2006. For example, this pattern was present for category 455 covering telecommunications advances:

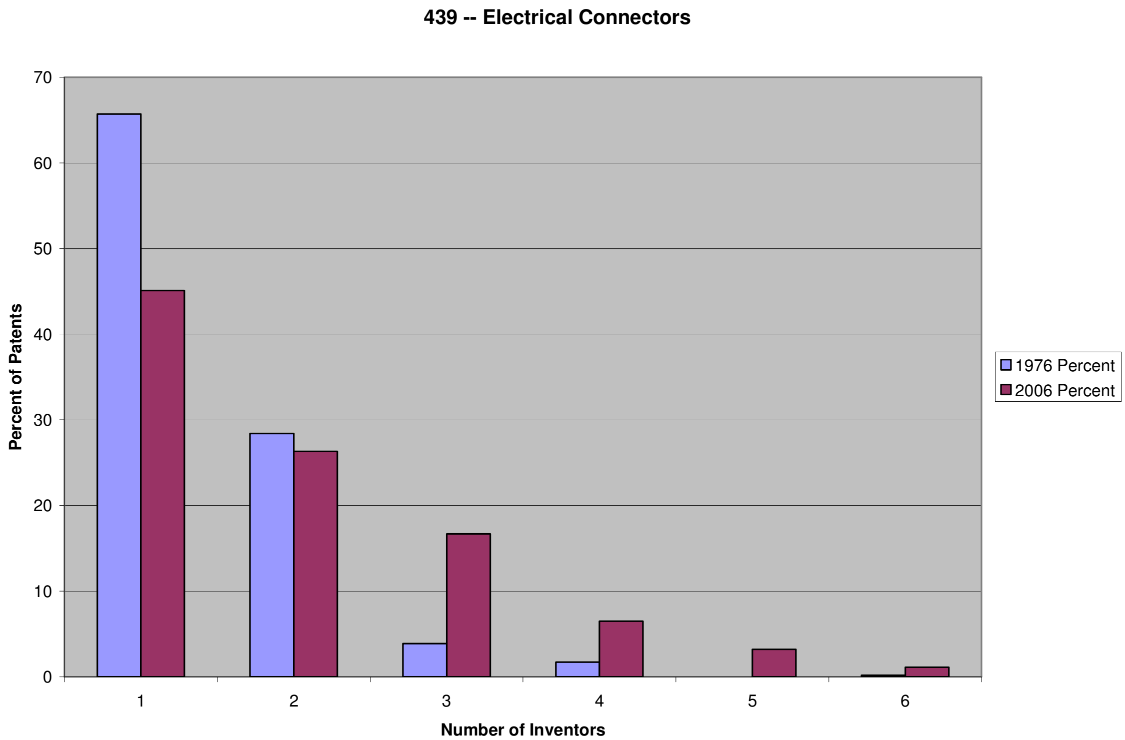
Figure 3



Apparently in this field and other fields with this pattern, the merits of group innovation only became clear with the advent of new communications technologies or other resources -- or different engineering methods or concepts -- newly available between 1976 and 2006.

Finally, in at least one technology area the changes in group innovation from 1976 to 2006 were small. This type of pattern was present for category 439 covering electrical connectors:

Figure 4



In this electrical design field, where design principles are relatively predictable, a single inventor or a small group of inventors can project a broad set of design consequences. With this level of predictability and the consequent ability of one inventor to project the consequences of complex design choices, the advantages of large group innovation appear to have been far less than in some other fields in both 1976 and 2006. The average size of inventor groups for this technology class was the smallest of all the technology classes studied in both 1976 and 2006.

However, even here, there was some increase in the prevalence of small size inventor groups between 1976 and 2006, suggesting some new benefits of group efforts because apparent in this area even if group efforts were not necessary to effective innovation. The perceived benefits of group innovation in these fields may be, for example, that larger groups can simply complete more innovative tasks at a faster pace and thereby increase the pace of innovation even though effective innovation at a slower pace is still possible through efforts of smaller inventor groups or solo inventors.

D. Impacts of Communication Advances in Enhancing the Effectiveness of Innovation Groups Across Great Distances

Interactions between innovators located at substantial distances from each other present especially difficult problems for innovation group managers. These problems were summarized by a group of recent analysts as follows:

> It is generally accepted that people work together best when they are physically collocated. Physical collocation facilitates communications, and therefore collaboration, that is responsive, efficient and spontaneous. Physical collocation in today's business world is not, however, generally practical even when workers are employed by the same company. The stresses associated with travel and commuting often prevent or impair the efficiency of bringing co-workers into physical collocation in order to facilitate job function.
>
> Modern telecommunications services facilitate collaboration among co-workers. Services such as the Public Switched Telephone Network (PSTN), the Internet, and related services such as facsimile, electronic mail, instant messaging, one-way and two-way paging services all contribute to enable and facilitate collaboration. As currently available, however, such services are not optimized to facilitate collaboration between team members.[49]

The degree to which distant displacement is a continuing barrier to effective innovation was a further focus of the present project. To study this, samples of 400

[49] United States Patent No. 7469384, "Method and System for Creating a Virtual Team Environment" (December 23, 2008).

randomly selected patents from each of the years 1976 and 2006 were assessed to determine the prevalence of inventor groups with at least one member who was sufficiently distant from other group members so as to probably preclude regular face-to-face interactions. The aim of this study was to determine whether changes in communication resources between 1976 and 2006 enabled greatly displaced groups to work more effectively.

For patents with two or more inventors and at least one inventor located in the United States,[50] the location of the inventors (as determined from the city locations indicated for the inventors in the patents) were assessed to determine if any inventor was more than 40 miles distant from the other members of the group.[51] If all the inventors in a group were located within 40 miles of each other, the patent was coded as involving "nearby" inventors. If at least one inventor was more than 40 miles from other members of the group, the patent was coded as involving "distant" inventors. All patents involving one or more United States inventors and one or more foreign inventors were coded as "distant." For patents involving groups of United States inventors, the distance between inventors was determined from the Google Maps web site, which reports the shortest driving distance between two points.[52]

50 No effort was made to assess the physical separation of foreign inventors in patents where the first named inventor was located overseas, suggesting that the advance and the research it was based on originated overseas. The physical separation of these foreign inventors would be an interesting topic of further study.

51 A distance of 40 miles was taken as a rough measure of the distance that inventors might drive or otherwise commute on a regular basis, thereby stating the boundaries of a community of innovators regularly interacting through physical face-to-face meetings.

52 *See* http://maps.google.com. United States patents identify inventor locations by

The results of these analyses are summarized in Table 9:

Table 9

Group Displacement Comparison

Group Type	**Number 1976**	**Number 2006**	**Percent 1976**	**Percent 2006**
Nearby	77	97	87.5	72.4
Distant	11	37	12.5	27.6

There was some increase in distant inventor groups between 1976 and 2006, but that the fraction of inventor groups with distant inventors only increased modestly and was small in both years. The percentage of groups with at least one physically remote inventor increased from 12.5 percent to 26.5 percent between 1976 and 2006. The Chi-square statistic for the percentages of nearby and distant inventor groups for these years equals 20.847 with 1 degree of freedom. This corresponds to a two-tailed p value of less than 0.0001, meaning that there is a statistically significant difference between the prevalence of nearby and distant inventor groups in 1976 and 2006. This indicates that the communication and other resource differences over this period appear to be facilitating a statistically significant difference in the amount of effective work conducted by innovation groups at a distance. Hence, these findings support that hypothesis that the prevalence of workgroups with widely separated innovators would increase with the implementation of the Internet.

---

city name. The Google maps service associates the location of a city with the location of its city hall. Hence, the distances used in this study for inventors were effectively the distances between the respective city halls of the cities involved, an approximation of the actual distances between inventor residences.

However, the impact of the Internet seems to have been relatively small in terms of the prevalence of innovation groups with widely separated members. In both years studied, the great bulk of invention workgroups were ones with physically proximate co-inventors, apparently reflecting the continuing difficulty of effective interactions across greater distances. These findings support the notion that pure electronic communications may only rarely be enough to support the many types of complex and detailed interactions needed to conduct group innovation, at least at the level of patentable advances.

E. Weaknesses in the Present Study And Possible Extensions

1. Uncertainty Regarding Independent Factors

The growth in the prevalence of innovative workgroups across the period between the two years studied, is unquestionably significant, but the source of these changes is still unclear. In particular, the influence of particular resource changes such as the advent of the Internet is still not established. What we know from the present results is that workgroups of increasing size were relied upon more and more for projects leading to patentable inventions in many technology areas. Whether the operation and inventive success of workgroups were facilitated by new communication resources such as the Internet cannot be determined from the present data.

Given the importance – both legal and practical – of effective communication between co-designers to produce patentable inventions by joint inventors, communications improvements such as those newly provided by the Internet remain one highly probable reason for the growth of group innovation during the period studied. However, there are many other plausible explanations as well.

For example, it may be that the fields of knowledge that were most commonly associated with patents issued in 2006 relative to those in 1976 have shifted more towards fields in which effective innovation is more readily achieved through group efforts. This would produce a shift towards greater prevalence in workgroup-produced innovations even if particular workgroups were no more effectively operated. Similarly, workgroups may have been more effectively formed or operated in 2006 than in 1976, but the reasons may have to do with other factors than the communication technology enhancements that occurred between those dates. Another possible answer may be that the more recently trained scientists and engineers who comprised most of the innovators in 2006 were more attuned to collaborative processes and more effective team members in workgroups than their 1976 counterparts.

The elimination of these and other possible explanations for the changes in workgroup size and geographic dispersion noted in the present study will require more sophisticated models and regression techniques that will permit controlling for the effects of other explanatory variables to determine if the advent of the Internet seems to have had a separate and significant impact. Such studies would also benefit from the use of data on workgroup size from patents issued in additional years. The present study, which clearly reveals the significance of changes in workgroup patterns from 1976 to 2006 confirms the merit and value of continuing to the next level to seek explanations for these socially important changes.

B. A Potential Impact of Changing Patent Law Standards

Another possible problem with the present study that would be avoided by using patent-derived data on workgroup size for additional years relates to a change in United

States patent laws that may have contributed to apparent changes in workgroup sizes. An amendment to the United States patent laws in 1984 added a provision which specifies that, where multiple parties have been working together on a single design project, one of the team members can still be a joint inventor and share in the ownership of a resulting patent even if the party did not "make a contribution to the subject matter of every claim of the patent."[53] This provision deals with circumstances in which multiple parties are working together on a single design project, but some of them are only working on some but not all of the versions or embodiments of the design at issue.

A group might, for example, work on a new chair design and develop a generally usable new design with a fifth leg. An additional member of the design team, who did not contribute to this basic design might still add the further thought that the fifth leg might be made of high strength steel to produce a particularly strong support. If a patent were sought and issued for both the basic design and the second design version involving the steel leg, the fact that the one team member only contributed to the design for the second chair version would not preclude that party from being a joint inventor and from sharing in the ownership of the patent as a whole. This reflects a change in United States patent law as of 1984, which previously provided (via case law) that a party must contribute to the designs reflected in all claims of a patent in order to be a joint inventor and to share in patent ownership.[54]

This change in patent law may have somewhat increased the number of joint

---

[53] 35 U.S.C. § 116(3). This provision was added to the Patent Act by Pub.L. 97-247, § 6(a), 96 Stat. 320; Nov. 8, 1984.

[54] *See* Andrew B. Dzeguze, *Avoiding the "Fifth Beatle" Syndrome: Practical Solutions to Minimizing Joint Inventorship Exposure*, 6 J. Marshall Rev. Intell. Prop. L. 645 (2007).

inventors associated with patents, since contributors to particular portions of claimed inventions would be added to the set of parties previously qualified to be joint inventors. This change in numbers of joint inventors due to the change in joint inventorship law is not thought to have added many new joint inventors as the parties additionally qualified as joint inventors under the new standards would have to be parties who were already part of the design teams that produced an invention, but just contributors to some but not all of the resulting designs. These limited but still substantial contributors to the joint inventions may have been few because the limited contributions of these parties would, in general, discourage them from being added to or maintained on an innovative team. Hence, the numbers of joint invention patents are not thought to have changed greatly due to the change in law in 1984.

A more complete set of patent data will inventor counts form more years would allow for determinations of whether inventor counts showed a substantial jump following the 1984 amendments to the patent statute.

V. **Conclusion**

The results of this study confirm the substantial growth in numbers of inventive groups producing patented inventions in 2006 over 1976, as well as the increases in average work group sizes among parties obtaining patents in many technology areas. These findings have implications for the training of engineers, the management of high tech projects, and the administration and development of patent law.

A. Training of Engineers and Scientists

For engineers and scientists who will comprise most of the parties working on high tech development projects, the importance of group interaction skills are clear from the findings of this project. Innovation projects at the highest levels – that is, projects leading to patentable advances -- are increasingly pursued through group efforts. The size of the groups needed to produce successful discoveries of patentable advances is increasing. Commercial entitles and universities that are strongly interested in advancing commercially significant projects through the development of patentable technologies will also be interested in identifying and involving persons who can work well with or, better yet, lead innovation teams. This emphasis on group projects will be particularly strong in fields like biology and chemistry where large group innovation has been predominant for many years.

B. Technology Project Management

As projects go forward, the importance of involving and coordinating the efforts of multiple contributors is also clear. This suggests several implications for technological project management. Teams with the right mix of participants -- that is, with parties who bring complementary expertise or skills to the project and can apply them in a coordinated fashion -- will tend to advance their efforts more quickly and effectively than teams that must identify and assemble needed expertise in the midst of a design projects. Also, where team efforts involve stages of design creation building on the partial work of prior stages, effective communication of work allocations and partial design results will keep group projects moving ahead with the least possible wasted time and effort. Management techniques and skills needed to achieve these sorts of efficient group efforts should be primary focuses of management training and improvement.

The challenge of effectively managing technology projects among groups spread across considerable distances appears to remain an important barrier to effective group action. The findings of this study regarding the physical separation of members of innovation groups suggest that most group innovation is still accomplished through regular face-to-face interactions. Even with the advantages of communication technologies such as the Internet, the fraction of innovation groups having at least one team member working at a long distance from other team members to produce patentable advances remains small. Group management practices for technology projects should be improved to make more effective use of design expertise and skills spread at a distance so as to achieve the same sorts of inventive design successes in physically separated innovation groups that are increasingly present in physically proximate groups.

C. Patent Law Implications

For patent law practitioners, the importance in the coming years of group innovation and associated legal issues regarding joint inventors is clear. The evidence presented in this study indicates that most patents issued in recent years are based on joint inventorship and involve the sorts of joint ownership issues that can make patent enforcement particularly complex.

In carefully operated organizational environments where all the relevant innovators work for the same company, university, or other research organization, the use of patent assignment agreements may simplify joint ownership problems by transferring all fractional joint ownership interests in a particular patent to one corporate or organizational owner. However, where all of the necessary patent assignments are not obtained due to administrative mistakes or where outsiders who are not part of a pre-arranged system of patent assignments are part of a group of co-inventors, convenient means to assemble full ownership of a patent in one party may not be present. In such circumstances, owners of partial patent interests may be subject to holdups by a co-owner who insists on being bought out on favorable terms on threat of resisting or interfering with some commercial venture in which the relevant patent is expected to play a key part.

Resolving joint inventorship questions and associated patent ownership problems may be particularly difficult as the size and complexity of innovation groups grows. The present study indicates that both the number and size of innovative groups producing patented inventions increased substantially between 1976 and 2006 and there is no reason to believe that further growth will not occur in the future. In addition, the range of technologies in which group innovation is a significant factor seems to be on the rise, spreading the contexts where joint inventorship problems will be increasingly common. The growing significance of joint inventors as confirmed by this project indicates the corresponding importance of joint inventorship laws and the need for renewed attention to legal standards in this area. These findings also highlight the importance of management practices for technology development projects that avoid legal uncertainties about the identity of joint inventors who will be patent co-owners as much as possible. Without care in these methods, technology innovators may face highly unwelcome surprises in joint inventorship determinations once patents are in dispute in legal proceedings.

D. Reassessing Basic Patent Law Standards for A Group Innovation Age

In addition to being increasingly concerned about joint inventorship standards and determinations, patent law specialists should focus new attention on how a variety of other patent law tests will apply to innovation that is largely conducted through group efforts. The factual determinations related to a number of patent law tests may be particularly difficult when innovations emerging from group processes are at stake. This subsection briefly suggests a few of the problematic determinations that may be necessitated by group innovations.

Basic patent law requires that a patentable advance -- that is an innovation that can qualify for a patent if a proper patent application is filed -- must have three types of characteristics.[55] First, it must fall within the range of patentable subject matter.[56] Second, it must be new and a substantial departure from prior knowledge in the relevant field of design or technology.[57] Third, it must be understood and described in a patent application with sufficient particularity to enable parties other than the inventor to replicate the invention.[58] This subsection scrutinizes these requirements as they apply to patentable advances produced by workgroups.

1. Patentable Subject Matter and Workgroups

Patentable subject matter is present if an innovation entails a new and useful device, material or process that is artificial (in that the innovation did not previously exist in nature but is instead man made) and that includes a machine or physical transformation of matter.[59] A wide range of physical items and processes ranging from new life forms

---

55 The requirements mentioned here describe important features that must be in all patentable inventions, but do not address all of the required features of patentable advances. For a more compete treatment of the standards for patentable inventions, see Donald Chisum, Chisum on Patents (2009).

56 35 U.S.C. § 101.

57 35 U.S.C. §§ 102(a), 103.

58 35 U.S.C. § 101.

59 *See Diamond v. Chakrabarty*, 444 U.S. 1028 (1980); *In re Bilski*, 545 F.3d 943 (Fed.Cir. 2008) (en banc).

to computer-based information processing advances fall within the range of patentable subject matter. Many of the most commercially successful advances in recent years have emerged from resource-intensive contexts in which group innovation (at least in the coordination of multiple resources needed to establish the potential for advances) is commonplace or even necessary.[60] In short, discoveries of some types of patentable subject matters may depend heavily on group innovation.[61]

Determinations of whether an advance involves patentable subject matter may be particularly difficult where the knowledge constituting an invention is spread among several parties in group innovation. The presence of a sufficient machine or transformation of matter in the innovative designs of a group of parties may be difficult to measure because some parties may, for example, develop the physical structures of an innovation while other members of a group may develop key ideas about how the device will operate. Whether these ideas are sufficiently integrated to produce a new machine or method of operation may turn on complex information about the scope and completeness of the interactions among innovation group members. The need to assess these factors will make statutory subject matter analyses for group innovation substantially more

---

60 *See* text at note 47, *supra*.

61 However, this is not the same as saying that these discoveries of complex technologies requiring resource intensive research demand group innovation. Efforts needed to produce new and useful designs may emerge from the work of a sole inventor serving as the focal point of a variety of support services and assistive personnel. Innovation in complex settings may still conform to somewhat of a "surgeon" model, where one key party is the sole innovation designer even though his or her efforts are aided by many important contributions from non-inventor assistants in the innovative process. *See* Fred Brooks, The Mythical Man-Month (1976) (describing the advantages in software design of using design teams based on this type of surgical model and the difficulties -- due to team coordination and communication programs -- of gaining productivity increases through adding team members to software coding teams).

complex than for individual innovation.

2. Novelty, Non-Obviousness and Workgroups

Patentable inventions must also not be previously known as shown by publicly revealed activities, publications, or patents.[62] A patentable advance must also be a substantial departure from prior knowledge such that the advance would not seem obvious to a well-informed practitioner with average skills in the relevant field of engineering or design.[63] These requirements drive innovators seeking patentable inventions to work towards advances that are outliers in their fields in that the advances will not conform to prior thinking in those fields (and may even go against commonly held predictions of innovation failure based on prior knowledge in the fields). Innovators pursuing patentable advances will instead seek to apply prior design knowledge to problems in new fields or will take fundamentally new design approaches to solve practical problems.

Combinations of expertise assembled through workgroup efforts may be particularly effective means to bring together either complementary technological knowledge or combinations of problem knowledge and technological solutions so as to produce useful designs that would not be possible through the efforts of single individuals and which involve the types of outlier advances that can qualify for patents. In essence, workgoups may be information gathering devices, bringing to the design table information held by each of the contributors to a design project. Provided that the information held by multiple participants can be extracted, coordinated, and combined in

---

[62] 35 U.S.C. § 102(a).

[63] 35 U.S.C. § 103.

effective ways, workgroups provide the promise of bringing previously disparate technical designs and expertise. Workgroups can also combine functional knowledge of technologies held by one or more individuals with knowledge of practical needs in a field held by other individuals and thereby produce inventions that would not be possible without this combination of expertise through group interactions.

3. Concreteness, Completeness and Workgroups

Patentable advances must reflect a workable design that is understood with sufficient particularity and completeness to be capable of written description in a patent application.[64] This involves meeting both knowledge and description requirements -- that is, a sufficient invention must be known in all its functionally important parts so that these can be properly combined and reproduced in subsequent efforts to replicate the invention. In addition, these component parts and the means to produce, combine, and use them must be actually described in a written patent application.[65]

Work on innovations through group efforts may potentially frustrate the type of complete knowledge needed for patentable innovations. Where different subcomponents of a potential advance are known by different parties in a workgroup, there may be substantial challenges in coordinating these portions of knowledge in an overall design. Furthermore, even where an advance produced by a workgroup is shown to operate once, it may be difficult to move from this operative example to describe how the component pieces of the invention (which may be based on the separately held knowledge and expertise of group members) should be produced and used. Combining the component

---

[64] 35 U.S.C. § 112.

[65] *See id.*

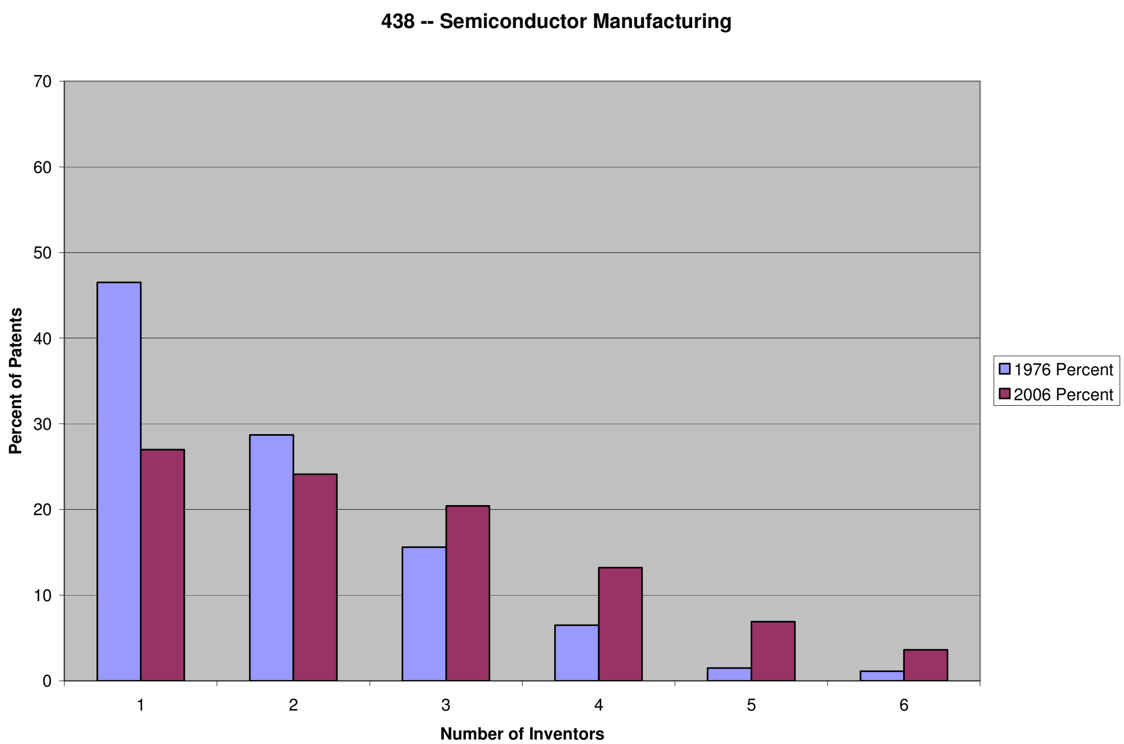
knowledge of workgroup members does not just involve coordination challenges at the time of design work on potential inventions. It also demands substantial effort to coordinate the descriptions of the full range of features of a successful advance where pieces of the advance have come from different parties joined together in a workgroup.

In sum, group innovation presents technological promise, management challenges, and legal uncertainties for the future. Attention now to related patent law standards will strengthen the clarity and impact of patent-influenced incentives encouraging the development of new technologies through increasingly important collaborative efforts.

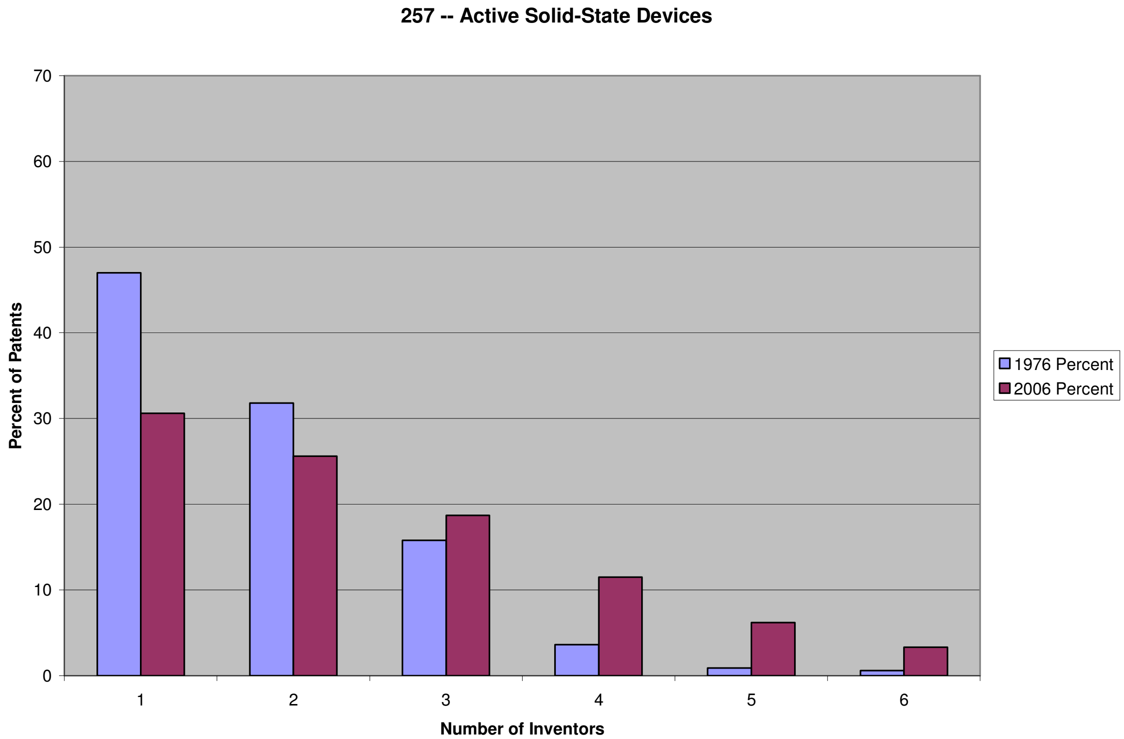
Appendix A

Comparison of 1976 and 2006 Inventor Group Sizes
for USPTO Primary Technology Categories

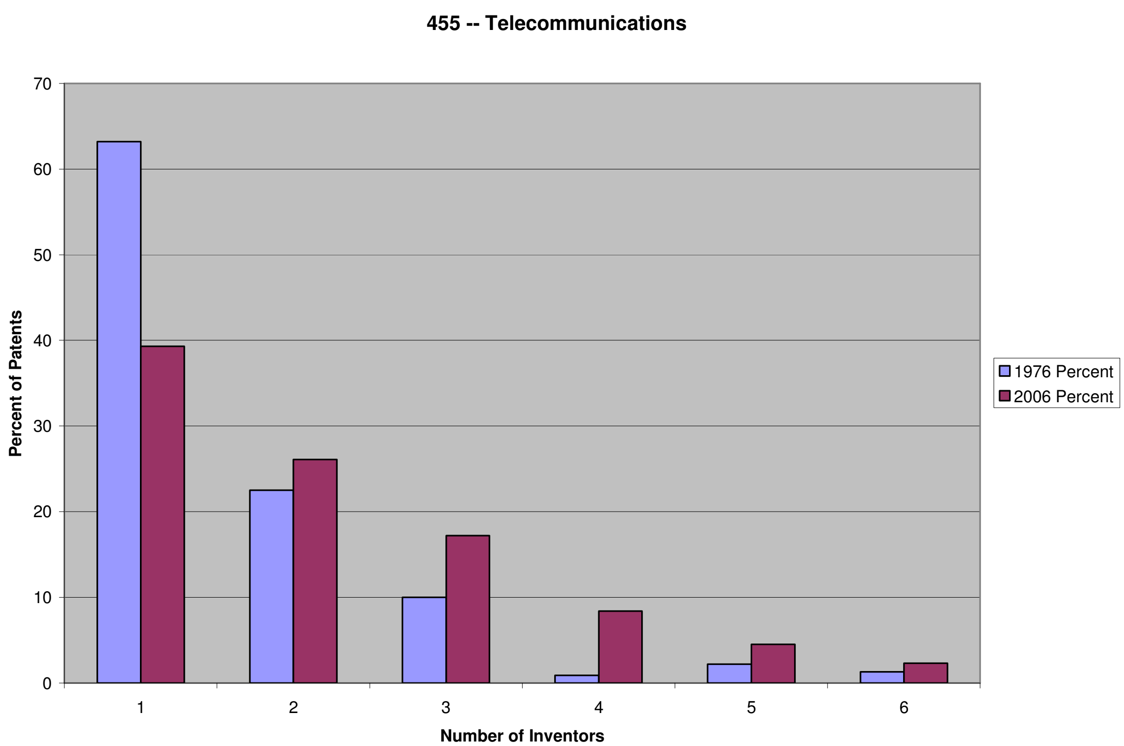
This appendix compares the distributions of inventor group sizes for the 20 USPTO Primary Technology Categories with the greatest numbers of utility patents in 2006. For each primary category (as listed in the title of the following charts), the percentages of inventions with each inventor group size are shown for both 1976 and 2006. Categories are presented in descending order of the number of utility patents in the categories in 2006. Chi-square figures for each category of patent were determined by using the group size counts for 2006 as observed figures and calculating expected counts for that year if the 2006 figures reflected the same percentage breakdowns for specific group sizes as the 1976 figures.



Chi-square = 2179.523 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

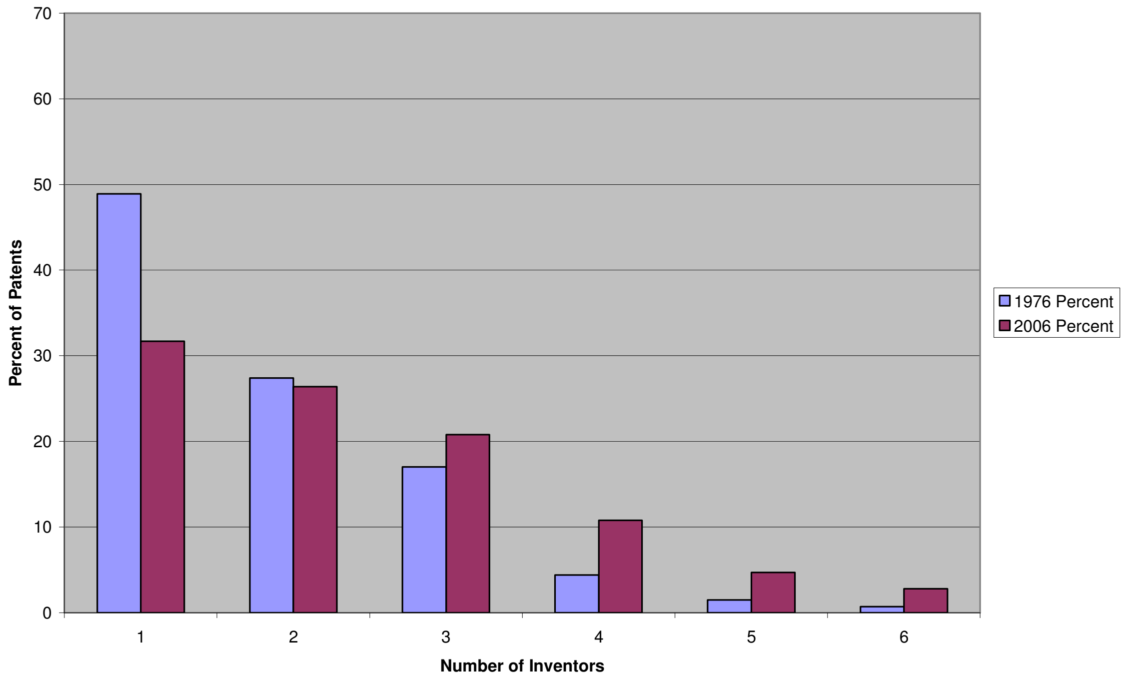


Chi-square = 3217.464 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level



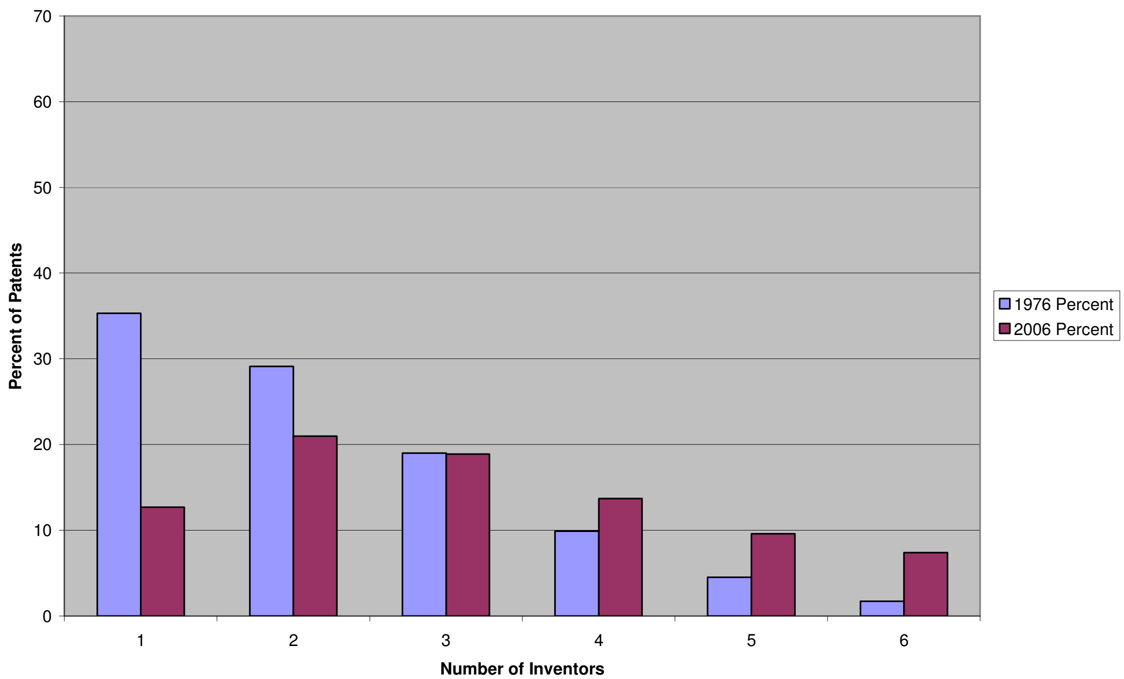
Chi-square = 3486.870 with 6 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level

370 -- Multiplex Communications

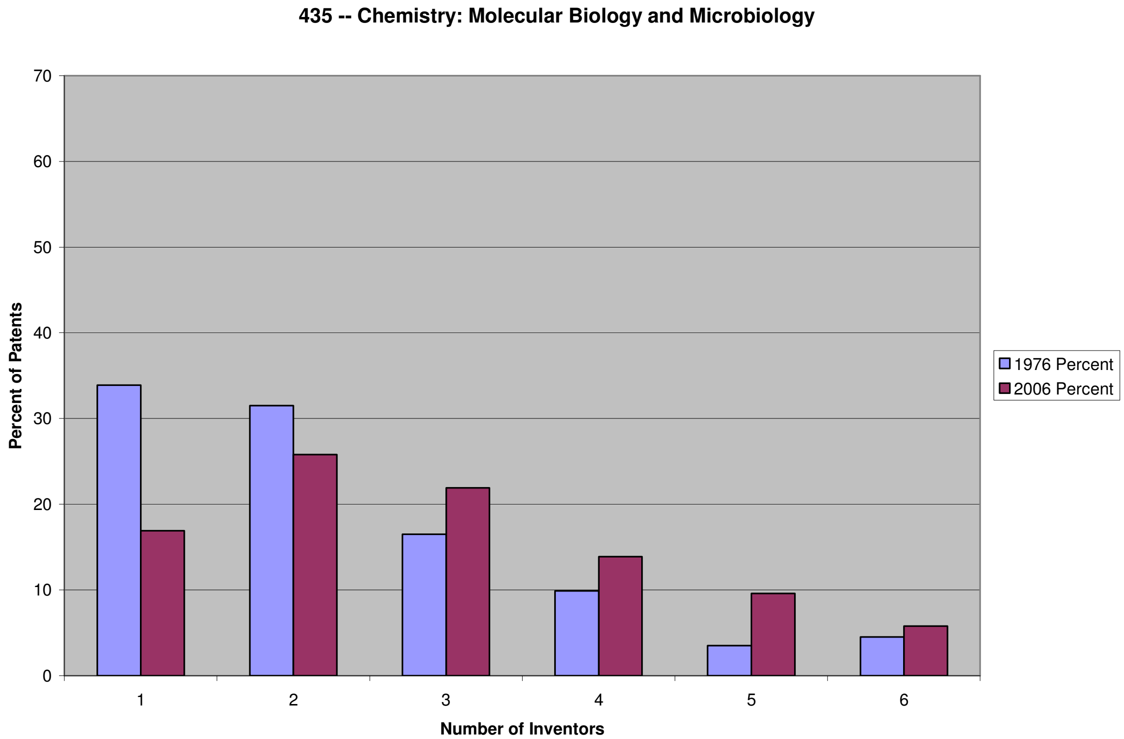


Chi-square = 1105.391 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

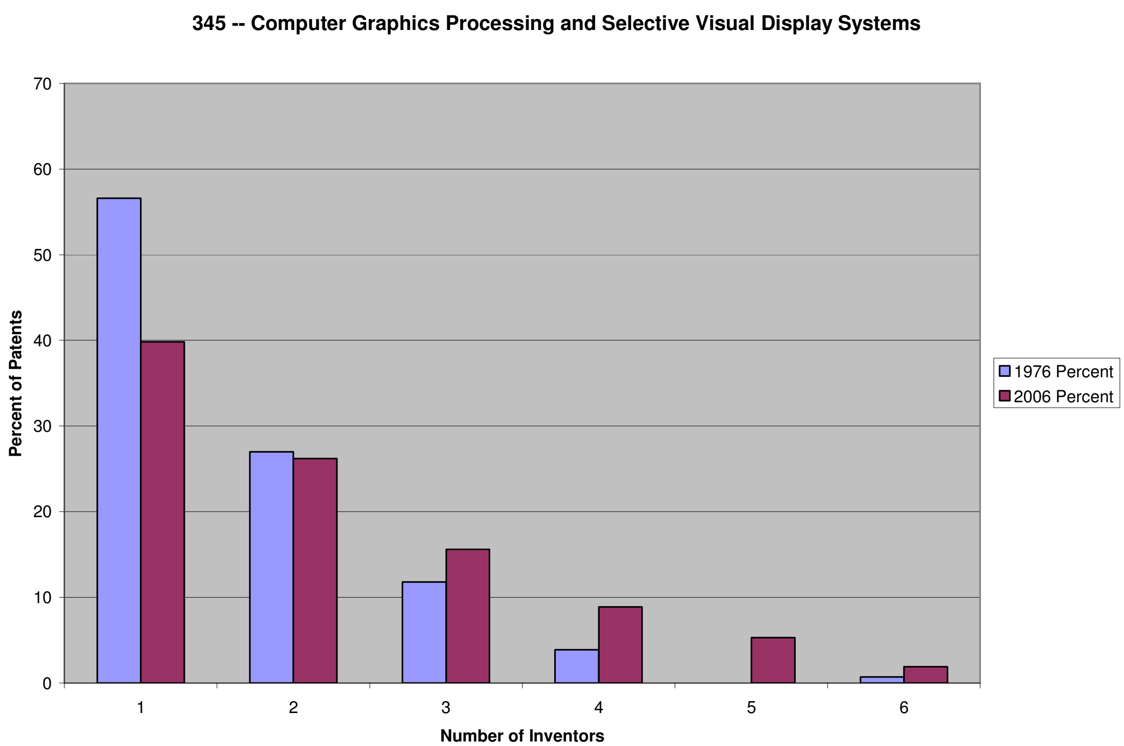
514 -- Drug, Bio-Affecting and Body Treating Compositions



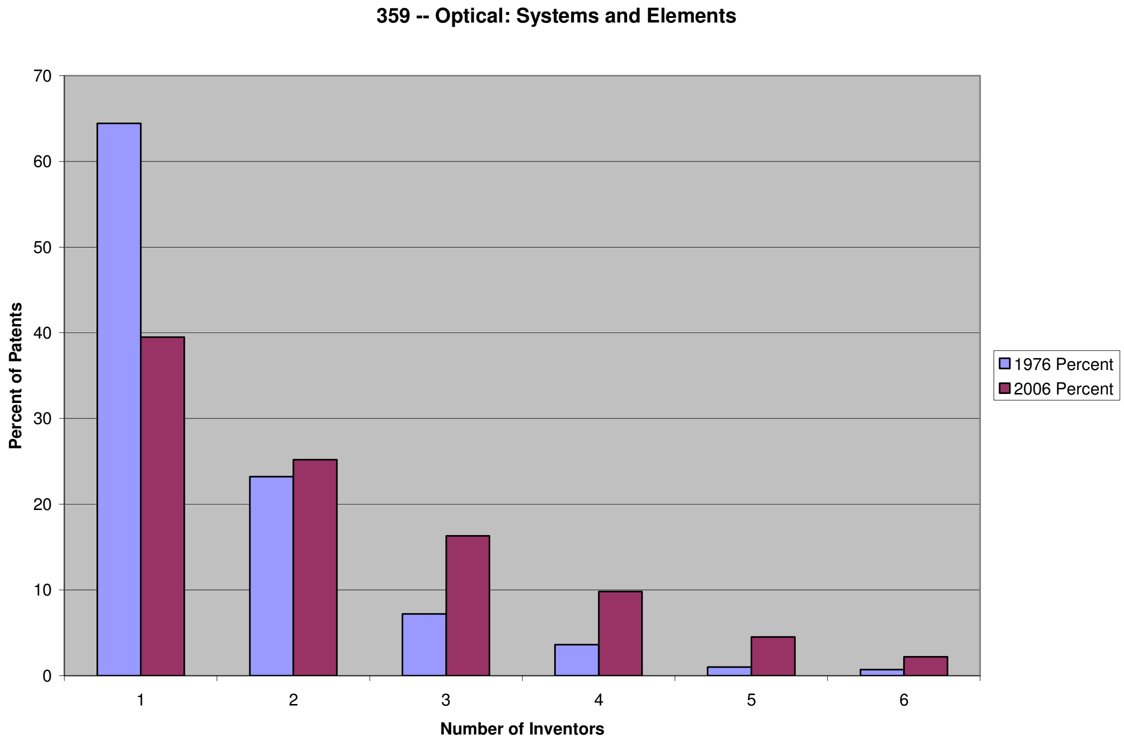
Chi-square = 1601.343 with 5 degrees of freedom, indicating the difference in percentages is significant at the p<.01 level



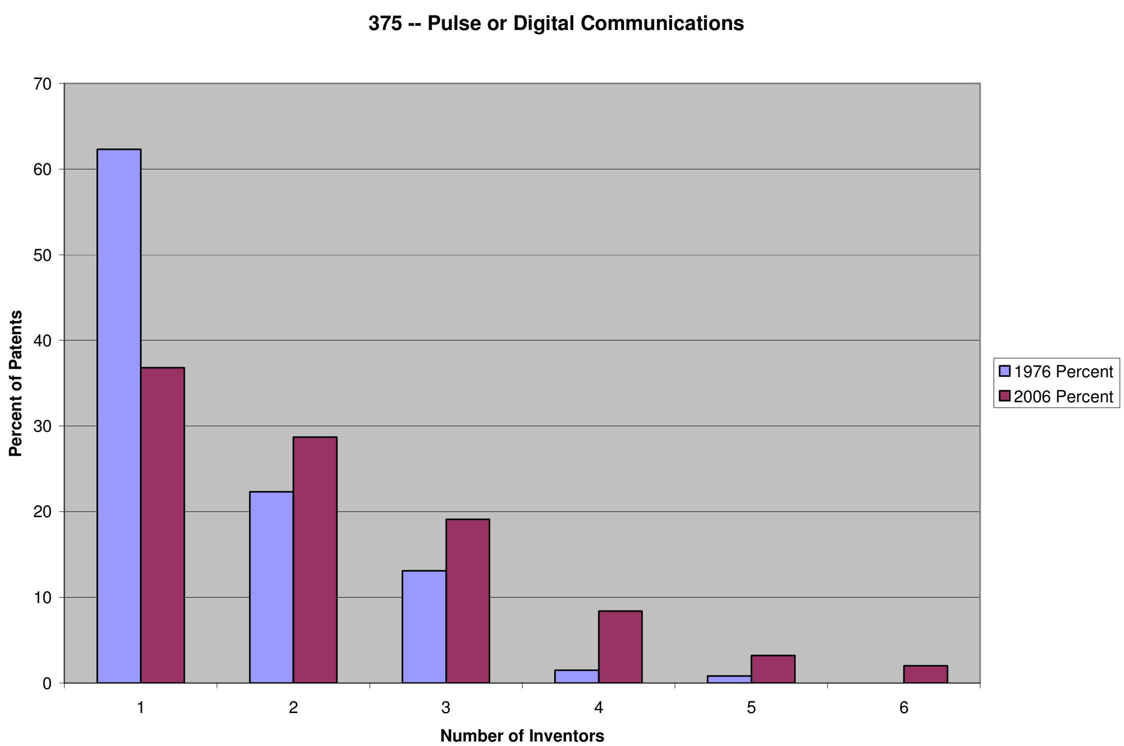
Chi-square = 780.668 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level.



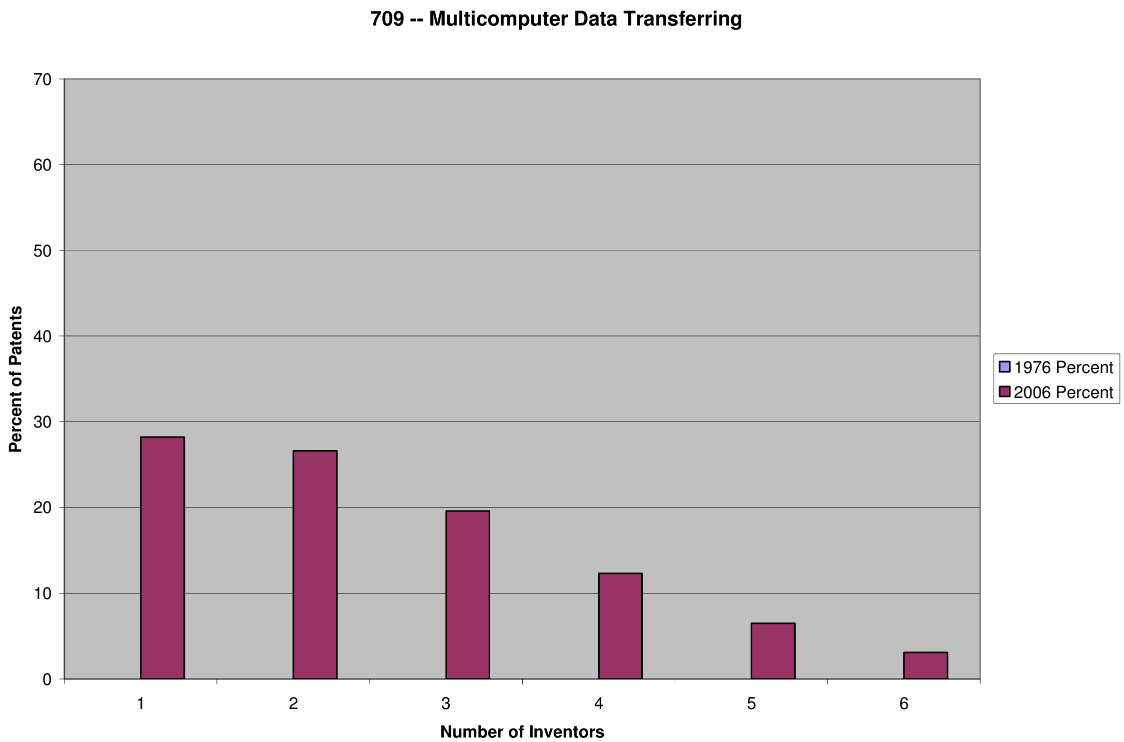
Chi-square = 1431.930 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level



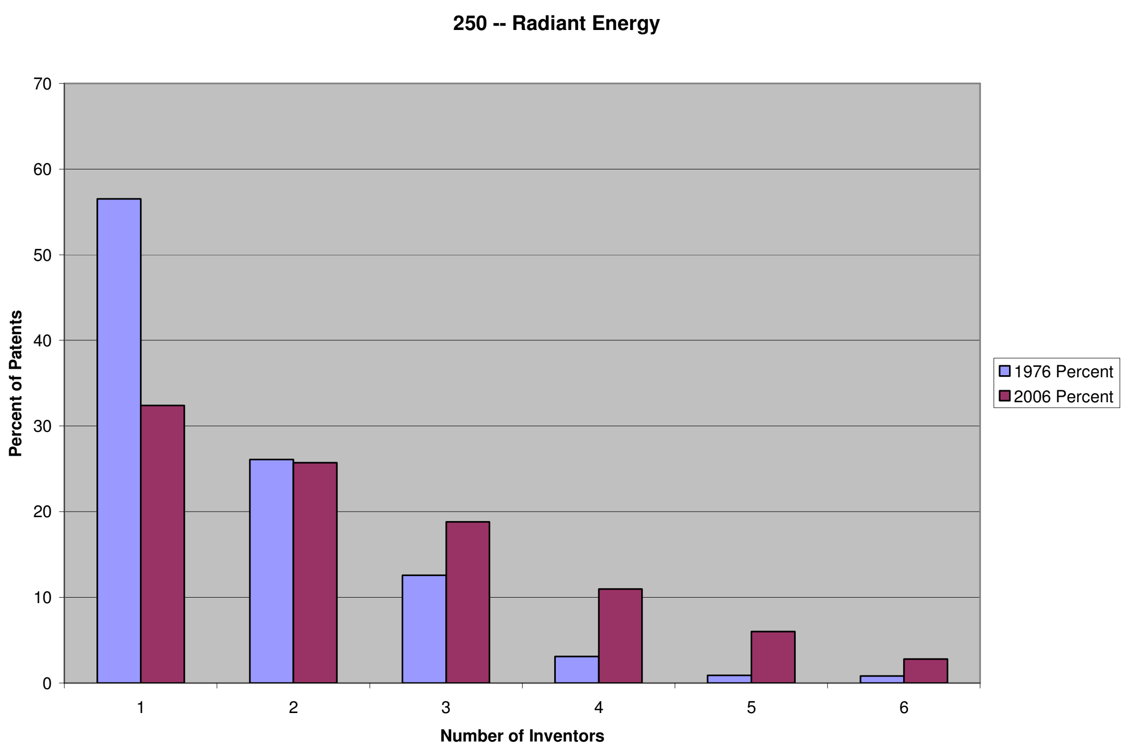
Chi-square = 1166.942 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level



Chi-square = 1335.877 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level

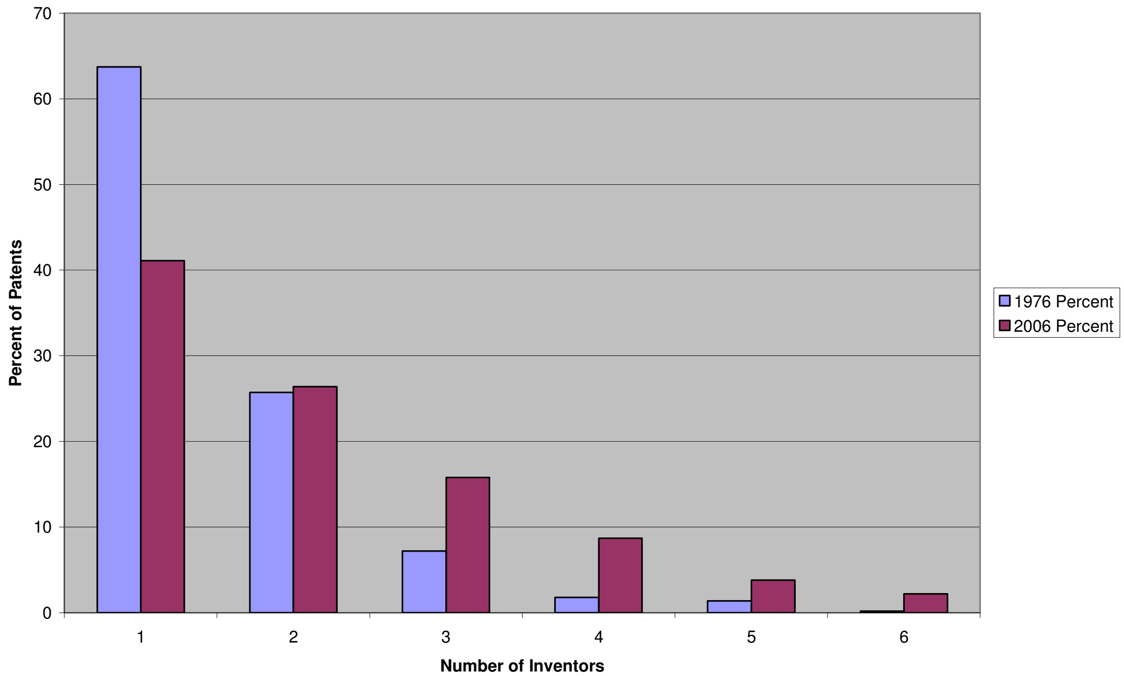


Category not used in 1976



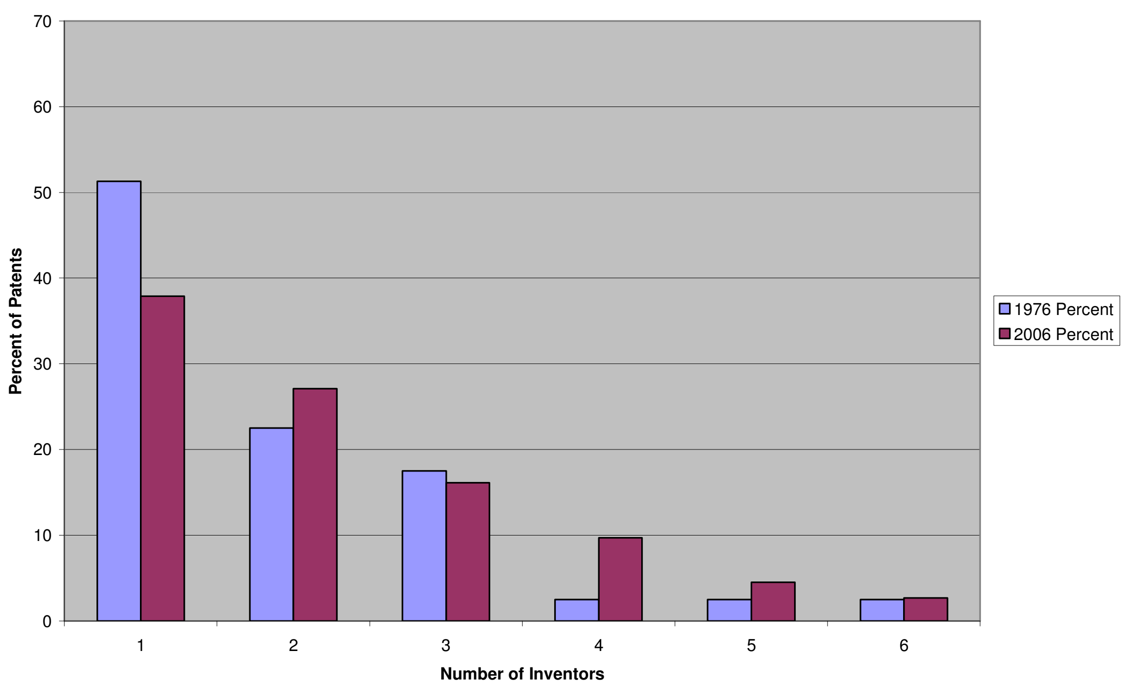
Chi-square = 1556.494 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level

340 -- Communications: Electrical

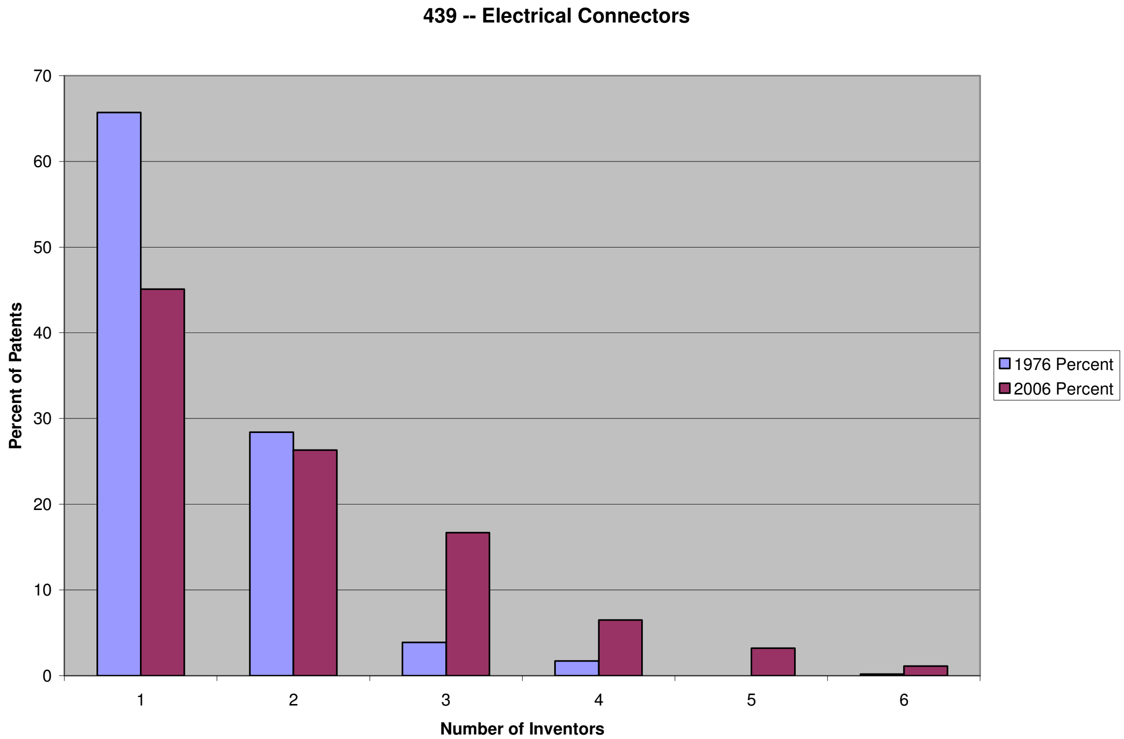


Chi-square = 1512.527 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

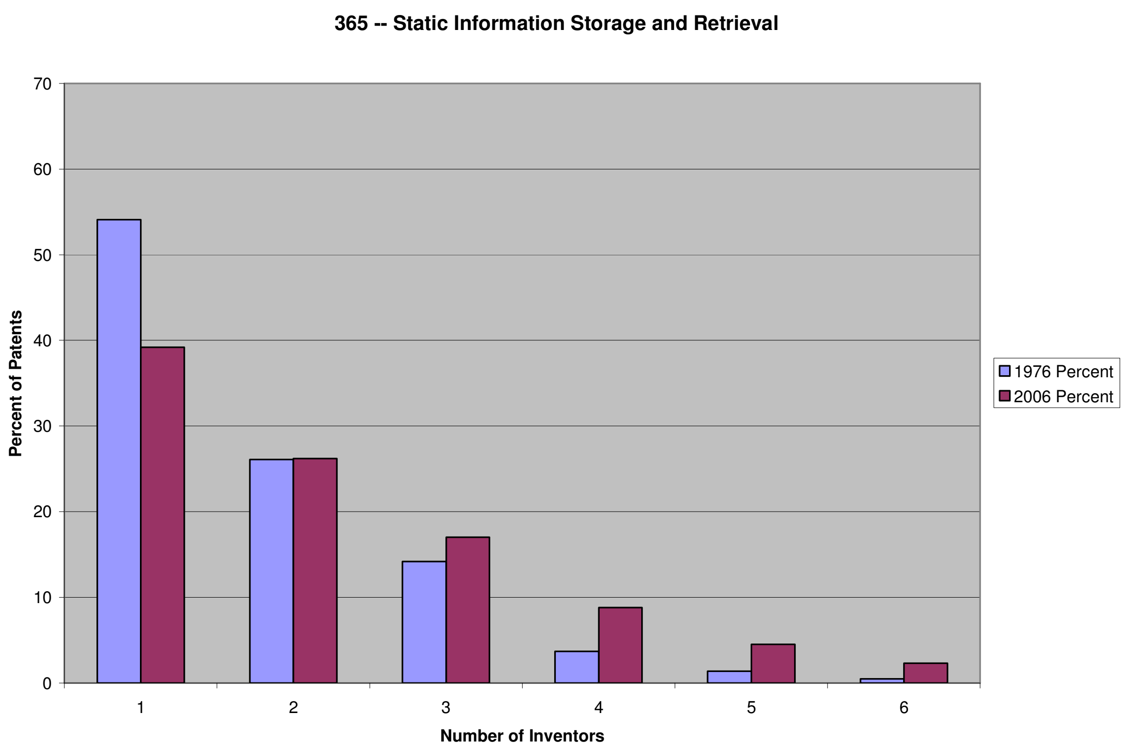
382 -- Image Analysis



Chi-square = equals 618.510 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

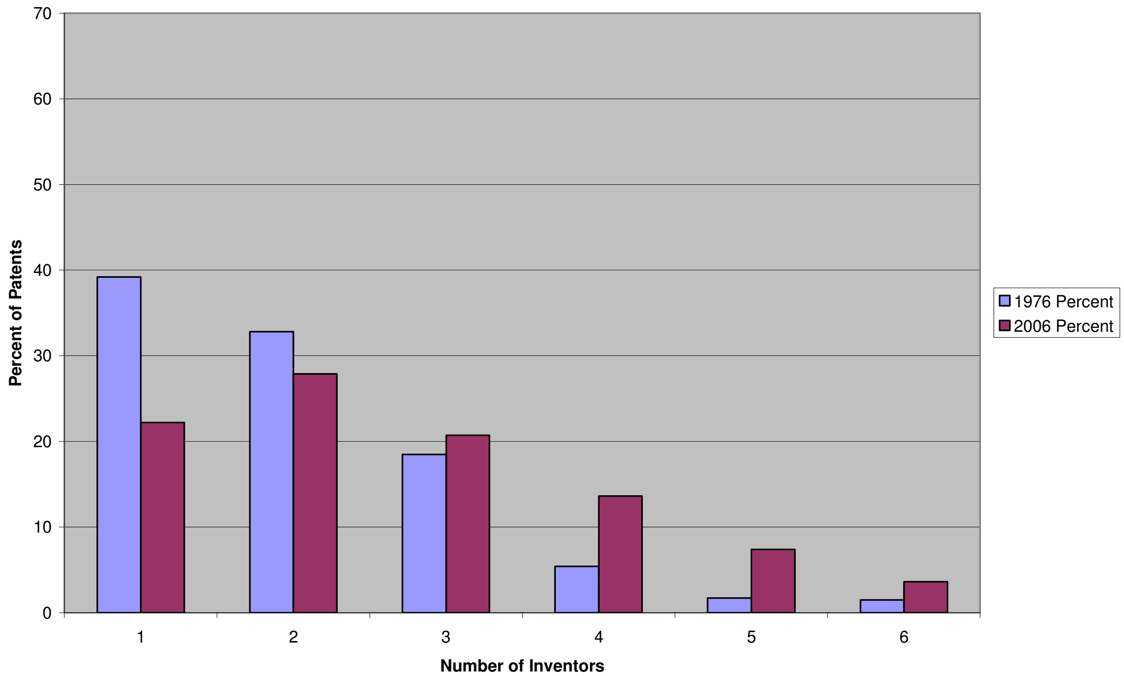


Chi-square = 2465.081 with 5 degrees of freedom., indicating that the difference in group size distributions is significant at the p<.01 level



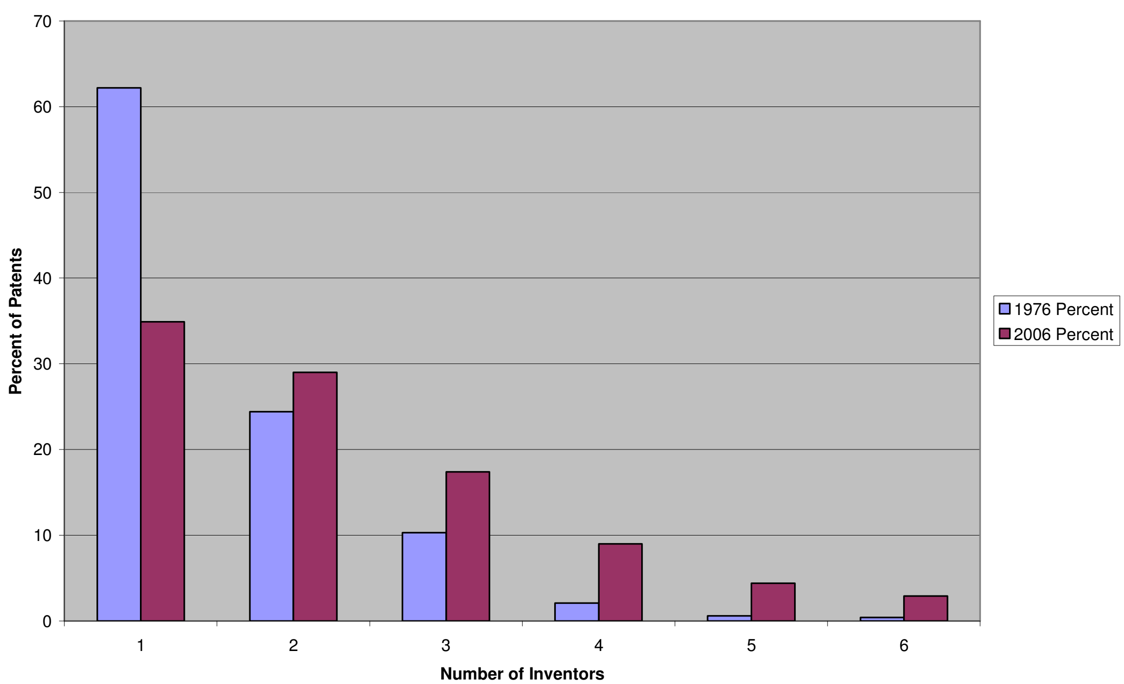
Chi-square = 585.274 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

424 -- Drug, Bio-Affecting and Body Treating Compositions

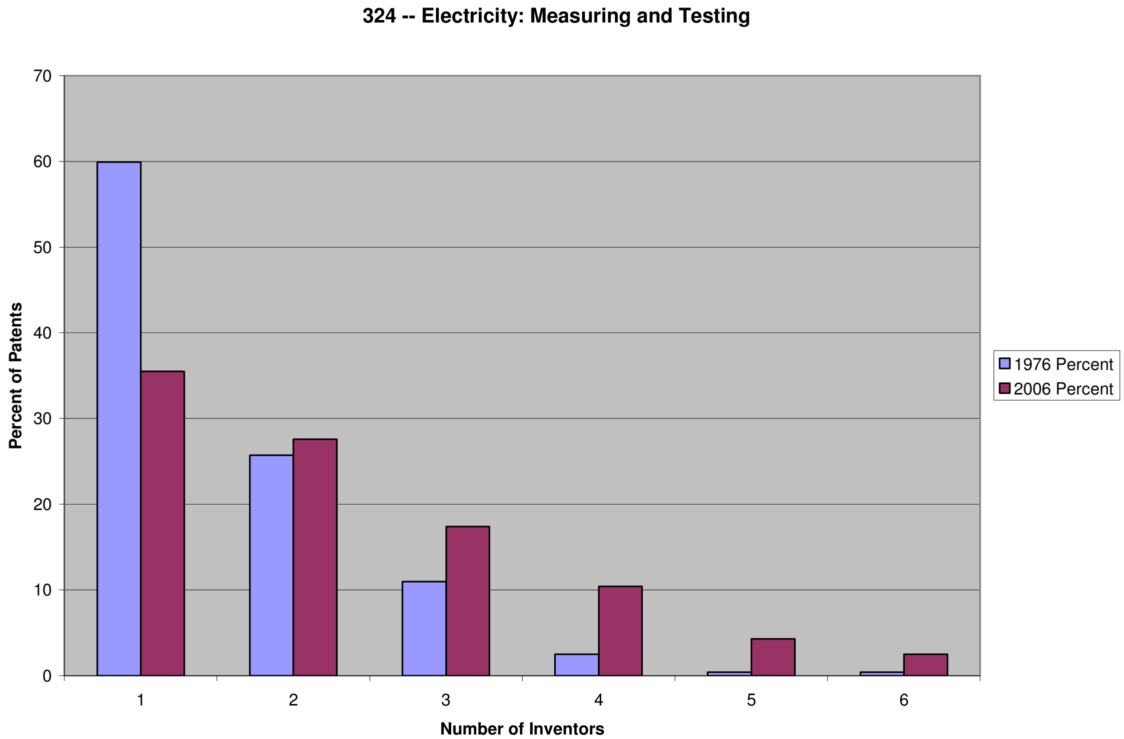


Chi-square = 961.507 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level

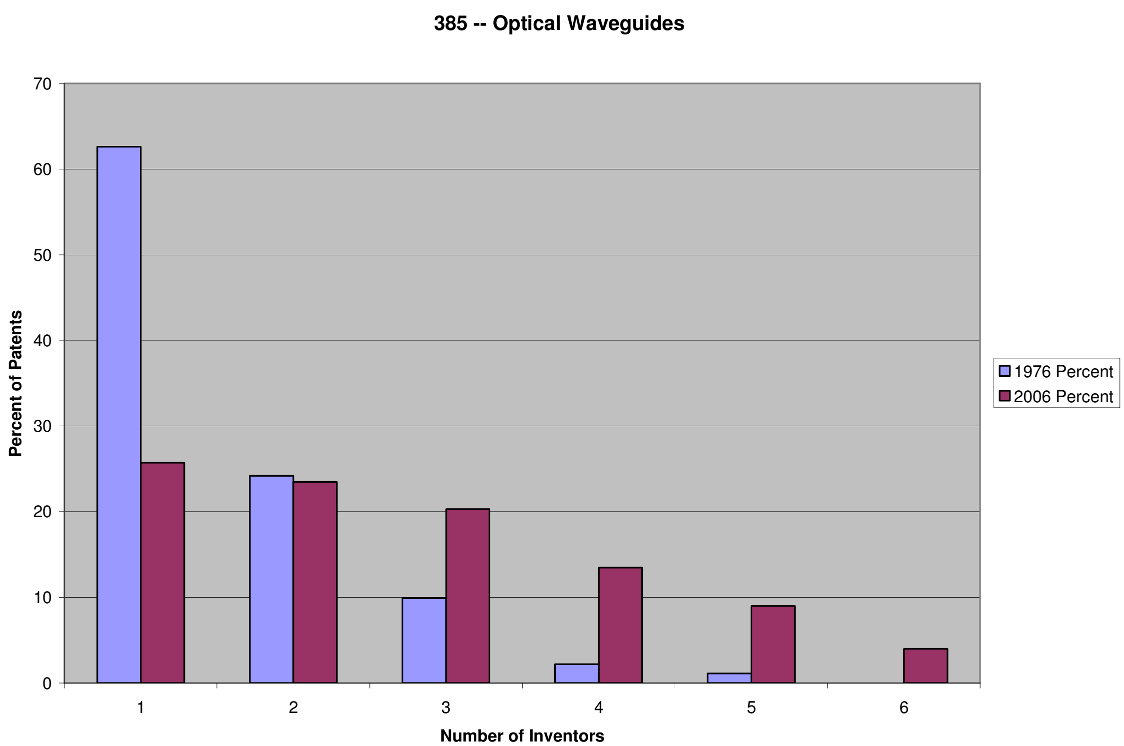
73 -- Measuring and Testing



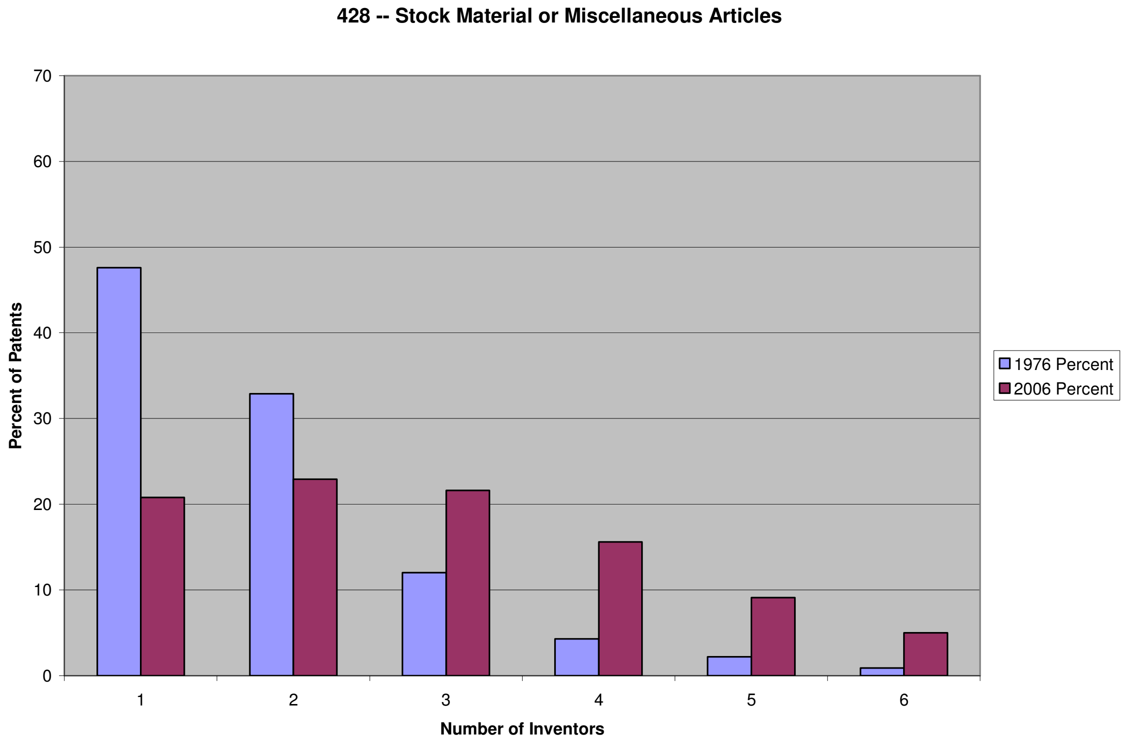
Chi-square = 1656.268 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level



Chi-square = 1694.222 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level



Chi-square = 3232.205 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the p<.01 level



Chi-square = 1977.651 with 5 degrees of freedom, indicating that the difference in group size distributions is significant at the $p<.01$ level