Today's Edisons: Technical Merit and Success of Inventions by Independent Inventors[1]

Kristina Dahlin[2]
University of Toronto, Rotman School of Management

Margaret Taylor
University of California Berkeley, Goldman School of Public Policy

Mark Fichman
Carnegie Mellon University, Graduate School of Industrial Administration

Abstract

This paper contributes to the debate about the value of inventions by independent inventors by comparing the technical merit and commercial success of patents by these inventors against those of corporate inventors in a consumer products industry. The findings demonstrate that independent inventors are over-represented among low-impact patents, while they also hold the most influential patents overall. In addition, we find differences in the scope and level of detail of patents by the two groups of inventors, as well as differences in patent maintenance at the first two fee points. We find no difference in the overall maintenance time span.

Keywords

Independent inventors, technical merit, commercial success, patents, innovation sources

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[2] Corresponding author. Rotman School of Management, University of Toronto, 105 St. George Street, Toronto Ontario, M6J1H2 Canada. Phone: 416.978.6179. Fax: 416.978.4629. Email: dahlin@rotman.utoronto.ca.

1. Introduction

Although independent inventors have historically been seen as important actors in developing new technologies, there is a debate in the innovation literature about whether their influence is as great today as in earlier times. Literature in favor of their continued importance states that radical inventions are more likely to be generated by industry outsiders and the organizational extensions of their apocryphal "garages" (e.g., Prusa and Schmitz, 1991; Jewkes et. al., 1969; and Schumpeter, 1939). There is also evidence that the development of new inventions by independent inventors is at a lower cost than similar inventions in large corporations. In one study, independent inventors were found to bring their products to market with development costs about one-twelfth those of established firms, with gross profit margins comparable to those found in the pharmaceutical industry (about 29%, Astebro, 1998).

But the iconic lone and "heroic" independent inventor – such as an Edison or a Kettering – is under threat by arguments that the ideas of most independent inventors are of less value than those generated by inventors within corporations. In this line of thinking, as invention has become more industrialized, independent inventors have become increasingly marginal contributors to innovative activity (Rosenberg, 1994). One indication of this is the decline in prominence of independent inventors in U.S. patenting: whereas independent inventors filed 86% of all U.S. patents in 1910, they similarly filed only 15% in 1998 (USPTO, 1998).[1] Some scholars claim that patents filed by independent inventors, on aggregate, are "relatively

[1] Alternatively, it should be noted that this decline might indicate less about the value of the inventions of independent inventors and more about the financial difficulties facing these inventors, since filing for a patent can be seen as the first stage in the commercialization of an invention. In recent years, the transaction costs associated with patent filing have increased while there has been a concurrent trend in the internationalization of patenting activity. Inventors in corporations are better suited to take advantage of both of these trends, as well as the increasingly common strategy of patent "blanketing" of a given technical field (Cohen, Nelson, and Walsh, 2000).

unimportant" (Narin, 1991). Indicative of this perception of independent inventors, as a group, is a quotation by the former Commissioner of the U.S. Patent Office, Bruce Lehman, who called independent inventors "weekend hobbyists" (Chartrand, 1999).

This debate has importance for policy, as evidenced by the way that policymakers respond to the financial constraints facing independent inventors. Many studies have demonstrated that financial constraints make independent inventors less likely to commercialize their inventions, concluding that these constraints comprise a market failure.[2] Indeed, one study shows that independent inventors are only about 17 to 25% as likely as inventors in already established firms to bring their inventions to the market (Astebro, 1998). Since potentially radical new inventions need to be supported at optimal levels or else society risks losing potential benefits, one of the central issues in entrepreneurship and technology policy has been to support independent inventors in their efforts to commercialize their ideas (Holbrook, et. al, 2000). If it is accepted that today's independent inventors have less valuable inventions as a whole than their corporate counterparts, the difficulties facing independent inventors in obtaining financing become fully justified market reactions of little interest to policymakers.

The aim of this paper is to evaluate the differences between the inventions of independent and corporate inventors in light of this debate and its policy implications. We chose to investigate one industry in a detailed manner in order to bring these differences to light most effectively. We study the tennis racket industry, which is a highly competitive and mature industry with significant innovations by independent as well as firm-based inventors. The peak

[2] There are three different foci of this work. First is the focus on the implications of financial constraints for the choice between paid work and self-employment (Bernhardt, 1994; Blanchflower and Oswald, 1990; Evans and Jovanovic, 1989; Evans and Leighton, 1989; Holtz-Eakin et. al., 1994a). Second is the focus on the determinants of the supply of capital to start-up firms (Bates, 1990; Evans and Jovanovic, 1989; Grown and Bates, 1991). Third is the focus on the rate of survival of small start-up firms, conditioned on their access to capital (Bates, 1990; Cressy, 1996; Grown and Bates, 1991; Holtz-Eakin et. al., 1994b).

year of racket sales in the U.S. was 1978, when 35 million Americans claimed to play tennis at least once a month, purchasing about five million new rackets (Tennis Industry Association, 2000; Sporting Goods Association, 2001). The peak-year of reported racket sales was 1976 when almost nine million rakcets were sold in the US. Corresponding with this peak was a peak in the number of firms active in the U.S. market with 62 firms offering at least one racket model for sale (the Sporting Goods Directory, 1960-1985). Participation in the sport declined to a low of 18 million players in 1985 buying 2.7 million rackets. The interest in the sport has since rebound and 22.1 million Americans reported that they played in 1991, while firm exit occurred with a delay, leaving 21 firms still active in the U.S. market by 1991.

At the peak of tennis participation in the U.S., the racket of choice had an expected life span of 1-2 years, was oval-headed, 60-70 square inches, and was made of laminated wood (Dahlin, 2000). This had been the dominant design in racket technology since the late 1920s, when the laminated wood racket replaced the solid-wood rackets that had been used for the previous 200 years. This dominant design was challenged by several innovations in the 1960s through the 1980s that have changed the competitive focus of the industry from cost reductions in manufacturing to product design and innovation that enhances performance along new dimensions (Abernathy & Utterback, 1978; Tushman & Anderson, 1990). For example, these innovations increased racket lifespan to at least ten years while they helped to raise the per-unit racket price. Despite the price increase overall racket frame revenues have declined and while the peak-year in market value was $392M in 1979, in 1994 the market value was $234M (all 1994 prices).

Dominant racket design was challenged in the 1960s through the 1980s in the dimensions of materials of composition and shape. Materials of composition began to change in tennis rackets in the late 1960s with the introduction of the wire spiral wound steel frame racket developed by French tennis pro and inventor Renee LaCoste and licensed to Wilson in the U.S. A "materials race" ensued after its introduction, which resulted in the development of high performance rackets made of fiberglass composites.[3] Shape changes began to occur in tennis rackets in 1976, when the 95-115 square inch oversized racket head was introduced. Few professional players adopted the first generation of oversized rackets, however, and it took until 1996 and the event of the super-oversized racket before a size limit was included in the official rules of the game.[4] Another shape-based challenge was presented in 1987 with the advent of the wide-body racket. This innovation stemmed from two papers on the physics of the tennis racket, which demonstrated that before any energy taken up by a traditional flexible, thin-beam racket frame can be given back to the ball, the ball has long left the strings (Brody, 1984).[5]

2. Models and hypotheses

Our objective is to evaluate the differences in value between the inventions of independent and corporate inventors using detailed measurement techniques. What is "value" in this context? We understand value to be closely akin to the technical merit of an invention, which, in a perfect world without market failure conditioned on access to financial resources, should be rewarded in the commercial success of the invention in proportion to its technical merit. The research questions we pose in this paper consider value as both an indicator of technical merit and of commercial success.

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[3] Typically in these composites, graphite fibers coexist in a matrix with different combinations of ceramics and other encapsulations.

[4] The rules of the game had no references to racket design due to the dominance of the wood laminate racket, even with the advent of rackets made of new materials (although such rules were discussed at the time).

[5] The wide body racket lies behind the current criticism of professional players being so hard-hitting that the audience for the professional game cannot keep up with the game.

The first question we raise is based on the definition of value as technical merit: What are the differences in technical merit between inventions generated by independent and corporate inventors? There are three aspects of technical merit that we hypothesize may vary by the source of the invention – independent versus corporate inventors – and may be relevant to the commercial value of an invention. First, there is the "impact" of an invention on ensuing innovations in the same product category, which is related to the originality of the invention. Second, there is the "level of detail" of an invention, or how well thought-out the invention is as communicated to observers. We hypothesize that this is an indicator of the realism and completeness of an invention. Third, there is the "scope," or extent of an invention (for example, whether the invention consists of an entire system or one small part of a system), which is an indication of its potential value. For each of these aspects of invention, we hypothesize that different sources will dominate.

2.1 Technical Merit

A. Impact

Many scholars and practitioners distinguish between inventions by their impact (e.g., Tushman and Anderson, 1986; Henderson, 1993; Henderson and Clark, 1990; Ettlie, Bridges & O'Keefe, 1984). In light of the debate over the importance of independent inventors, we expect that the impact of the inventions of independent and corporate inventors will be distinguishable in ways that are not straightforward. The previously mentioned evidence that industry outsiders have a greater tendency to create radical innovation – with inherently greater uncertainty than incremental innovation – implies that independent inventors are more likely to have a population of inventions that are more variable in their range of impact than those of corporate inventors.

The great impact of some of these inventions is supported by the rationale that industry outsiders have a greater incentive than corporate inventors to challenge dominant designs in novel ways, since they have no older product generation to protect and are less vested in the assumptions and problem-solving methods of the industry (Schumpeter, 1939; Reinganum, 1983; Henderson & Clark, 1990). In addition, the typical work experience of the independent inventor – who often has a background in an industry different from the industry being invented in – also lends weight to the novelty, and hence, great impact of his or her inventions (von Hippel, 1988).

The lesser impact of these inventions can be inferred from the flip side of the argument above: while freedom from an industry's preconceived notions in some cases may lead to valuable and novel new inventions, in other cases, the absence of intellectual support provided by the corporate setting may lead to more marginal inventions. Lack of access to the knowledge sources that firm-based inventors have means that many independent inventors will be less aware of such things as the performance dimensions important to users, the more effective design features of rackets, and so on. In this way, we believe that both the evidence about the importance of independent inventors and the assertions of the marginality of independent inventors may find support in an intensive study of a single technology (Hughes, 1989; Lamberton, 1971; Petroski, 1992; Narin, 1994a; USPTO, 1998; Chartrand, 1999). Thus, we hypothesize that:

<u>Hypothesis 1A</u>: Independent inventors will be over represented in the populations of both high and low impact inventions.

B. Level of detail

The level of detail of patents is often variable, and we believe that this reflects to the observer how well thought-out the invention is and the sources of innovation the inventor has access to. Differing resources affect the sources of innovation available to independent and corporate inventors. Corporate inventors are better able to access the technology-specific knowledge and experience embedded in internal libraries, in-house experts, and long-standing relationships with outside experts because of the long-term involvement of corporations in a particular technology area. In addition, corporate inventors benefit from interaction with the development process, the manufacturing process, and with customer relations as additional sources of inspiration for research (von Hippel, 1988). Thus, corporate inventors have greater access to multiple generators of potential inventive insights connected to a single product line than do independent inventors; these sources of innovation should help make corporate inventions more detailed. We hypothesize that:

Hypothesis 1B: Independent inventors will patent with a lower level of detail than corporate inventors.

C. Scope

Most case descriptions of technical change describe invention as problem-driven (e.g., Hughes, 1989; Jewkes, et. al, 1969; Petroski, 1994). That is, an inventor starts working on a perceived flaw in a product and that flaw focuses the inventor's attention; as Petroski (1992) expresses it, "form follows failure." In line with this reasoning, it is natural to expect that independent inventors will generally focus on flawed sub-parts of products that they have noticed problems with, rather than on entire products. Corporate inventors, on the other hand, may be conditioned by their industries to focus their inventive attention on a different set of problems. For example, corporate inventors based in mature, consumer goods industries will have their attention focused by the cycle of new model releases to work on the development of whole new products, rather than on problems with sub-parts of existing products. In addition, we expect that corporate inventors will have an interest in both product and process design, while independent inventors will have much less interest in how a process is manufactured. Based on this, we hypothesize that:

Hypothesis 1C: Independent inventors will generate inventions of less scope than corporate inventors.

2.2 Commercial Success

The second question we raise in this paper is based on the definition of value as commercial success: What are the differences in the commercial success of inventions by independent and corporate inventors? Although previous studies such as Astebro (1998) indicate a lower commercialization rate for independent inventors, for consistency we need to reestablish these results with the inventions used to understand technical merit in this paper. Based on previous studies, therefore, we hypothesize that:

Hypothesis 2: Inventions by independent inventors will be less commercially successful than inventions by corporate inventors.

3. Data sources and methodology

3.1 Data sources

The data source we use to operationalize the differences in technical merit and commercial success of inventions created by independent and corporate inventors is a subset of U.S. patents. Patents have several advantages as a data source for this study. First, patent citation analysis has been widely used in the literature to assess the inventive impact of a patent (Hall, Jaffe, Trajtenberg, 2001; Harhoff, D., 1999; Lanjouw, J.,1999.; Albert et. al., 1991; Carpenter, Narin, and Woolf, 1981; Jaffe, Trajtenberg, and Henderson, 1993; Narin, 1994a; Narin, 1994b; Narin and Olivastro, 1988; Trajtenberg, 1990). This measure is what we use to evaluate our technical merit hypothesis concerning impact.

Second, patents are required by law to reveal the details of the technical merit of an invention that allow it to surpass the thresholds of novelty, usefulness, and non-obviousness necessary for the granting of patent rights. The claims section of the patent, in particular, outlines the content of the invention and defines what the inventor is granted monopoly rights to.

While past studies have used patent claims in order to provide an informed basis for patent comparison, we use them in a detailed way in order to assess our technical merit hypotheses regarding the level of detail and scope of a patent (Tong & Frame, 1994).

A third advantage of the use of patents in this study is that patent analysis provides insight into not only the technical merit of an invention, but into its commercial success as well. Although it can be argued that the act of filing for a patent is the first stage in the commercialization of an invention, the main way patents have been used to measure commercial success in previous research is through analyzing the payments of patent maintenance (or "renewal") fees by inventors. These fees, which increase over time, have been levied on patents filed on and after December 12, 1980. They are due at 3.5, 7.5 and 11.5 years from the grant date to ensure the full monopoly rights of the patent (USPTO, 2000).[6] Research using renewal fee information uses the period of time over which renewal fees are paid in order to assess the private economic value of a patent to its owner (c.f. Taylor, 2001; Lanjouw et.al., 1998; Pakes and Schankerman, 1984; Pakes and Simpson, 1989). In order to track the commercial success of a relatively large sample of patents, we chose to focus on patents granted between 1981 and 1991 because enough time has intervened since these patents were granted for inventors to have been faced with paying all maintenance fees.[7]

The tennis racket industry had three main patent characteristics that were helpful in this study. First, the industry has for the last twenty-five years had a high propensity to patent, according to both the industry association and one of the leading firms (Chen, 1998; Patterson,

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[6] Failure to pay maintenance fees results in suspended monopoly rights: a granted patent will have a minimum of four years protection, but lapse after than if the maintenance fee at 3.5 years is not paid. If the first maintenance fee is paid, the patent will be valid for an additional four years and then lapse after eight years if the fee at 7.5 years is not paid. If this fee is paid, the patent will be valid until year 12 after granting when another fee has to be paid in order to ensure the full protection period.

[7] Five of the 225 patents had their fees due at the time of analysis, although payment status was not yet recorded.

1996).[8] Second, the concordance between the SIC code and the patent classification for tennis rackets is close to perfect (the four-digit SIC code for tennis racket firms, 4939, matches the patent class 273/73+ "tennis rackets and parts"); this reduces the possibility for error in understanding patenting behavior in the industry. Third, the tennis racket has a long history of patenting activity that includes a significant number of patents by independent inventors. Of the 225 U.S. patents granted in tennis rackets between 1981-1991, 147 patents (65%) were granted to independent inventors and 78 (35%) were granted to corporate inventors. Table 1 breaks these inventors down by various descriptors, including their experience patenting in areas other than tennis rackets.

Insert Table 1 about here

These pools of patents by both sources of invention are large enough to perform statistical tests on the distributional differences between the inventions of independent and corporate inventors. In addition, we have indications that the patenting behavior of firms and independent inventors are similar. Both groups are patenting as soon as they have a patentable invention and they think they might have a market (Chen, 1998).[9] Both groups also appear to use patent lawyers to the same extent, as the firms are typically too small to have their own in-house legal teams and seem to draw attorneys from the same pool of legal firms that the independent inventors use.

[8] The propensity to patent differs across products, based on such factors as the nature of the technology and the competitive conditions in an industry (Cohen, Nelson, & Walsh, 2000; Brouwer and Kleinknecht, 1999; Cohen and Levin, 1989).

[9] There has historically been a large number of infringement law suits emphasizing the importance to patent in order to protect intellectual property.

Table 1 also highlights some differences across the groups: while firms in our sample on average hold 248 patents, independent inventors hold 8. While only 9% of the included firms have no other (US) patents, 44% of the independent inventors in the sample hold no other patents. At the same time as independent inventors on average are less likely to hold other patents, they are more likely to hold patents outside the sporting goods area. We found that many inventors that were patenting as individuals in the tennis racket arena, patent in other technologies under the name of a firm. We therefore conclude that many of our independent inventors (a) work in research and engineering, (b) are tennis players and (c) pair these two activites by redesigning their own sports equipment and patenting their designs.[10] The data in Table 1 indicates that independent inventors are a heterogeneous group and that blanket statements about their abilities might not be valid.

3.2 Methodology

Our construction of measures for *impact, level of detail, scope*, and *commercial success* was the most important element of the methodology for this study; for this reason we discuss these measures in some detail here. Our measure of *impact*, for example, is the number of times the patent has been cited as prior art in subsequent tennis racket patents granted up to June 2002. We weighted the impact score to control for annual variations in patenting frequency and for the fact that older patents have a greater opportunity for citation by subsequent patents than do younger ones (see Appendix A for the equation calculating impact).

In order to measure the *level of detail* and *scope* of patents, content analysis was performed on the 2,215 claims of the 225 tennis racket patents by both populations of inventors

[10] An example is an individual who works for Xerox Corporation in NewYork State, writes papers on the mathematics of sport and holds a number of tennis racket patents in his own name.

(independent and corporate). This content analysis was based on a code scheme we developed to capture three categories of information: the racket part the claim concerns (for example, the entire frame, the handle, the throat, the strings, etc.), the technical objective of the claim (for example, to make a stronger racket, a larger sweet spot, enhance the durability of a frame, etc.), and the innovative content of the claim.

This innovative content category consists of information on two hierarchical levels. At the first level, the characteristics of each claim were coded based on up to four descriptive categories: (1) Manufacturing process; (2) Design; (3) Material; and (4) Structure or combination of materials. The second hierarchical level was more specific and subdivided each of the four first-level categories into between five and sixteen sub-categories (see Appendix B for the complete code scheme). Each claim can be coded in multiple categories. As an example, the first claim of patent 4,685,675, "Adjustably weighted racquet," states:

> 1. Adjustably weighted racquet, comprising a head having a frame, said frame having a given number of holes distributed throughout said frame sufficient for completely stringing the racquet, said frame having a plurality of bores distributed throughout said frame, each of said bores being spaced from said holes, means for varying the weight and weight distribution of the racquet after string have been inserted in all of said holes without disturbing the strings, said varying means being in the form of a plurality of individual weights each being insertible in a respective one of said bores and being individually movable from bore to bore without disturbing the strings for weighting the racquet as desired, and means for detachably locking said weights in said bores.

Patent 4,685,675 has nine claims, of which claim 1 (by far the longest) is presented above. Under our scheme, this claim is coded as mentioning the entire frame (code PD1); suggesting the addition of new parts (code D1, for the individual weights); mentioning how the new parts should be attached to the frame (code D2); and where the new parts should be placed (code D8). The remaining eight claims add more information about where the bores should be placed, how they lock the weights in place, the shape of the weights (non-circular to prevent rotation), and the number of bores, which may exceed the number of weights. In total, the coders assigned nine codes for product parts for this patent (one for each claim). All of these codes were in one subcategory, as they pertained to the entire frame of the racket. There were no manufacturing codes given, nor were materials or material structures discussed. Nine design codes were also given – involving the addition of a new element, the attachment of a part, the size of a part, and the relative placement of the part on the frame – for a total of four subcategories (three of them D1, D2 and D8, as indicated above).

Two coders assessed all claims from the 225 patents according to this scheme. Both coders coded twenty percent of the patents for validation purposes. Inter-rater reliability was determined using Cohen's kappa, with the resulting kappa, z-value, and standard deviation scores reported in Table 2. The kappa-score is of key interest; according to Fleiss (1981), a score above 0.75 shows very good agreement between coders. As Table 2 demonstrates, coders agreed at far greater than the 0.75 kappa level for all but one of the descriptive categories, Design, which still had an acceptably high kappa score of 0.74.

Insert Table 2 about here

To construct the *level of detail* measure, we studied two aspects of the description of the invention in the patent claims. One aspect is the overall detail of the description, or the *patent detail*. This measure was defined as the sum of all the content codes the patent received, based on a count of categories (1) through (4) above. The second aspect of interest is the level of detail of a patent's claims, or the *claims detail*. To obtain this measure, we divided *patent detail* by the number of claims of the given patent. While *patent detail* and the number of claims are highly correlated (0.86), *claims detail* has a close to zero correlation with the number of claims in a patent (-.08).

Whereas *patent detail* and *claims detail* describe the depth of a patent, *scope* describes the breadth of a patent. To capture this breadth, we use two different measures. The first, *product scope*, considers how many parts of a racket the patent covers. A patent that only covers one part, such as the throat piece, is said to have a more narrow scope than a patent that covers multiple parts or the entire frame. The second scope measure, *scope of innovation*, considers whether the patent is about product innovation, process innovation, or both. This measure is binary, and answers whether the patent is about one or two dimensions of the product/process combination.

As mentioned above, our measure of *commercial success* was the payment of maintenance fees for the 225 tennis racket patents granted between 1981 and 1991. Recall that patents filed in 1981 or later are eligible for the payment of at least two of these fees; in addition, 120 of our 225 patents were granted between 1981 and 1987 and are thus eligible for the payment of all three maintenance fees. In our construction, *commercial success* begins as a binary measure in which a "successful" patent has had all relevant maintenance fees paid, while an "unsuccessful" patent has had at least one relevant maintenance fee left unpaid so that the patent's rights were allowed to lapse. The unsuccessful patent was then distinguished by the length of time that the patent owner chose to maintain it.

3.3 Analysis

Patent data is inherently skewed. In our data, this can be seen in the distribution of claims per patent (the patents in this population had between 1 and 53 claims with a mean of 9.84) and in citation counts (see Figure 1), while it can be expected in pay-off structures and in the number of patents per assignee.[11] None of the variables we used to test our hypotheses exhibit the characteristics of a normal distribution. Many of our variables are also counts, so since we are interested in testing the differences between populations of patents held by independent and corporate inventors, we rely on tests of medians rather than means. Thus, we use the Wilcoxon rank-sum (Mann-Whitney) test and Person's χ^2 of independence for the entire, or parts of, distributions, which are more suitable for testing comparisons between non-normal distributions with high levels of kurtosis (Sprent, 1993; StataCorp, 2001).

We avoid sampling issues because our two populations are analyzed in total for the period 1980-1991; any difference we observe is, therefore, a true difference. We test differences between the populations statistically because we see the time-period and the choice of technology as two ways to sample from many possible populations and we are interested in the likelihood of the findings holding with changes in these variables.

4. Results

4.1 Technical Merit

Table 3 shows descriptive statistics for technical merit in the tennis racket population according to inventor source. In addition, figures 1-3 display competing distributions by inventor source of some of the technical merit variables.

Insert Table 3 about here

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[11] The top 10% of patents can be expected to account for 48-93 percent of the total returns of a class of patents, while most assignees can be expected to hold 40 patents or less with a small number of assignee outliers, such as IBM, granted thousand of patents in a given year (Scherer & Harhoff, 2000).

A. Impact

Hypothesis 1A states that the inventions of independent inventors will be of both greater and lesser impact than the inventions of corporate inventors. This hypothesis therefore predicts that both the right-hand and left-hand tails of the impact distribution depicted in Figure 1 will be larger for independent inventors. An omnibus χ^2-test of the inventor source impact distributions depicted in Figure 1 tells us that the distributions are significantly different, but not in what way (see Table 4 for test results). A test of medians reveals that the distributions have the same proportion of observations above the population-level median, although they have significantly different standard deviations. In other words, the differences between the two distributions are, indeed, in the tails.

Insert Figure 1 about here

A closer look reveals that independent inventors are responsible not only for especially high-impact patents but also for a disproportionate number of low-impact patents. The difference between the highest-impact patents of independent and corporate inventors was large; the two independent inventor patents with the highest impact scores (42.8 and 37.5) are 2.2 and 1.5 population-level standard deviations higher, respectively, than the corporate patent with the highest impact score (26.6). Unfortunately, the distributions are not dense enough in the high-impact range to have reasonable power in a formal test, but the magnitude of the difference between the high-impact patents of these inventor sources echoes the notion, discussed earlier, of the "heroic" independent inventor.

The distributions are denser in the low-impact range, and formal tests demonstrate a significant difference in the proportions of independent and corporate patents that inhabit the lower 20% of the impact distribution (see Table 3). The overall range of impact values is between –8 and +42; impact values below 2 are associated with 70% of independent inventor patents as opposed to 30% of corporate inventor patents. This finding echoes the "weekend hobbyist" theory of the independent inventor.

This study thus provides evidence in support of both of the competing schools of thought on the modern impact of inventions by independent inventors, while tying them together in a more complex vision of the innovative role of the independent inventor. This vision is premised on the uncertain nature of the radical innovation that independent inventors are more likely to be associated with. In addition, this study has a methodological implication: in studies of inventive impact, both the left and right-hand tails of impact distributions are necessary to test.

B. Patent Detail and Claims Detail

Hypothesis 1B states that independent inventors will patent with a lower level of detail than corporate inventors. Recall that we operationalized "level of detail" according to two measures, *patent detail* and *claims detail*, where *patent detail* is the summation of the content codes for a patent and *claims detail* is the *patent detail* divided by the number of claims of the patent.[12] This hypothesis was therefore tested according to each measure.

Analysis of the distributions of independent and corporate inventor patents according to *patent detail* shows that the medians do not differ significantly (see Table 4 for test results and Figure 2 for the distributions). The overall distributions *are* significantly different from one another, however, as are the variances of these distributions. The corporate inventor distribution has a higher variance, mainly because of a longer tail in the high-*patent detail* end of the distribution. The independent inventor distribution has a larger proportion of patents with low-

[12] The latter measure corrects for the size of the patent, which is especially important in instances when a choice is made by the inventor (or the inventor's patent attorneys) to break a large patent into smaller patents.

patent detail than the corporate inventor distribution, with a significant difference between the proportion of patents in the bottom 20% of the distributions (85% of independent inventions are in this range as opposed to 74% of corporate inventions).

Insert Figure 2 about here

Analysis of the distributions of these inventor source patents by *claims detail* results in more explicit evidence for a lower level of detail for patents by independent inventors. Both the rank-sum test and the comparison of medians show that corporate inventors' patent claims are more detailed than are the independent inventors' patent claims (see Table 4 for test results and Figure 3 for the distributions).

Insert Figure 3 about here

Our tests demonstrate lower levels of detail for patents by independent versus corporate inventors. In interpreting this, it is important to consider what the "level of detail" of a patent indicates to a patent reader, which is a question we only begin to reflect on here. Consider the case of an independent inventor who hopes to cultivate potential investors by demonstrating how well thought-out and realistic his or her invention is. Ensuring that his or her patent has a high level of detail may reasonably be one way for the independent inventor to accomplish this. The finding that independent inventors have less detailed patents than corporate inventors, however, implies that any such patent strategy is swamped by conditions related to inventions by corporate inventors. We believe that the condition that is reflected in this finding is the greater access to multiple generators of potential inventive insights of corporate inventors, but only future research will be able to interpret this result more definitively. Here, it is enough to raise awareness of a dimension of technical merit in which independent and corporate inventors differ that might have implications for commercial success as well as policy intervention.

C. Scope

Hypothesis 1C states that independent inventors will generate inventions of less scope than corporate inventors. Recall that we use two different measures to operationalize scope: *product scope* considers how many parts of a racket the patent covers, while *scope of innovation* considers whether the patent is about product innovation, process innovation, or both. We find that our results differ depending on the measure of scope we use. We expected independent inventors to hold patents of less scope. While this is the case when measuring the *scope of innovation* as corporate inventors are more likely to craft patents that contain specifications about both the product and the manufacturing process, the results for *product scope* are not as straightforward. We found no difference in the number of parts considered in the patented inventions of the two groups of inventors, but we did find that independent inventors are more likely to patent inventions concerning the overall racket than are corporate inventors (see Table 4 for test results).

Insert Table 4 about here

4.2 Commercial Success

Hypothesis 2 states that independent inventors are likely to have less commercially successful inventions than corporate inventors. In keeping with the main way patents have been used to measure commercial success in previous research, we analyzed the payment of patent maintenance fees and defined commercially successful patents as those patents that are fully maintained throughout our period of study. According to this definition, only 25 percent of all the tennis racket patents in the dataset are commercially successful, a statistic that does not vary significantly by inventor source (see Figure 4 for the distribution of patents by commercial success).

Insert Figure 4 about here

Among unsuccessful patents, however, there are differences between the fee payments of independent and corporate inventors. Table 5 separates out the proportions of unsuccessful patents by the two inventor sources into the three patent periods possible – patents expiring after 4 years, after 8 years and after 12 years, and Table 6 presents results of tests of proportions across the two groups. Independent inventors are significantly more likely to maintain their patents beyond the 4-year period than corporate inventors (71% vs. 57%). The opposite is true after the 8-year period, when 59% of still-valid independent patents are renewed in contrast to 71% of still-valid corporate patents. By the time the third maintenance fee is to be paid at 12 years, 28% of all independent inventor patents and 24% of all corporate inventor patents are still valid. In total, only four of the still-valid patents at eight years are allowed to lapse at the twelve-year renewal point.

Insert Table 5 about here

The differences between the two groups are mainly at the first two fee points. This appears to reflect the documented strategy of independent inventors in this technology area who try to license their inventions to firms in the industry (Chen, 1998). While a corporate inventor is unlikely to file a patent without a known use for the invention, an independent inventor will file a patent and then try to find a licensor for the invention in what may be a lengthy process. The period of uncertainty about the value of an independent inventor's patent is thus likely to be longer, which helps explain the longer maintenance of inventions that are in the end not fully maintained.

Insert Table 6 about here

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5. Conclusion

In this study of the differences in technical merit and commercial success between inventions created by independent and corporate inventors, we tested patents in a highly competitive consumer products industry with a high propensity to patent and a strong patenting role for independent inventors. We expected significant differences between the two inventor categories, and while we generally found the differences we predicted, the details of these differences were at times surprising. In this section, we briefly reiterate these findings and provide some additional analyses, particularly regarding preliminary linkages between technical merit and commercial success.

Our most controversial finding is probably the evidence this study provides in support of *both* the "heroic inventor" and the "weekend hobbyist" schools of thought on the modern impact of inventions by independent inventors. On the one hand, the patents with the greatest impact in the population belonged to independent inventors; on the other hand, independent inventors were more likely than corporate inventors to patent inventions that had little impact. This finding gives credence to both sides of the policy debate on the importance of independent inventors, while it shows that each side may be focusing on only one part of a two-part picture related to the great uncertainty involved in pursuing radical innovation. The question for policymakers in this shifted context is therefore at what cost should society support independent inventors who are tied to radical innovation, given the wide range of impact of their innovations overall.

A further question involving innovative impact is whether there is a role, as set out in Podolny and Stuart (1995), for the status of an actor to help determine the impact of his or her invention; as operationalized in their work, this boils down to correlations between prior patents owned and likely impact on other players. A brief analysis of the players with highest impact in our study reveals little such correlation (indeed, the owners of the two patents with the highest impact scores in this dataset hold no prior patents). Symmetrically, the firms with the most patents in our study do not appear to have a greater impact than other firms. These findings remove the confounding influence of status from this discussion of impact and lend weight to the suggestion, in line with Albert et al. (1991), that inventive impact is related to inventive novelty in this industry.

We have two additional findings related to the technical merit of an invention. First, we find that the patents of corporate inventors are more detailed than inventions by independent inventors. This is particularly true in our analysis using the *claims detail* measure. As outlined in our results discussion, this difference is most interesting if we can contextualize what the level of detail of a patent means to a patent reader; this is a subject for future work. Based on our current research, we believe that the level of detail of the patent does have commercial implications. Subsequent analysis using the measures of detail and commercial success in our study shows a very low correlation between the level of detail of a patent and the length of time an inventor maintains it (0.11 for *patent detail* and -0.05 for *claims detail*). Although this is not a strong finding, it does indicate a possible avenue for further research.

Our analyses regarding a third dimension of technical merit, patent scope, showed contradictory outcomes. Not surprisingly, we find that firms are not only more likely to file patents concerning process innovations, but are also more likely to file patents that outline a combination of new product design and an associated manufacturing process. More intriguing is a follow-up finding that independent inventors are more likely to patent innovations involving the entire racket than are their corporate competitors. In follow-up work, we find a 0.26 ($p<.01$) correlation between product scope and the length of time a patent is maintained, implying that larger scope inventions may be more rewarding for inventors. When controlling for type of inventor, the results are slightly different: the correlation between product scope and maintenance time is higher for corporate owned patents (.38 at $p<.01$) and lower for independently owned patents (.22 at $p<.05$).

The final aspect of the comparisons we made looked at the periods of time over which the two inventor groups chose to maintain the patent rights for their inventions. The payment of patent maintenance fees is a well-accepted measure of commercial success, which we expected to be able to use to differentiate the two inventor groups. To our surprise, we found that there is virtually no difference between the two groups when looking at the likelihood of maintaining a patent throughout its maximum patent protection period. One possible explanation for this finding is that in the tennis racket industry, the market for innovations from independent inventors is strong (as intimated by our findings regarding inventive impact).

Differences occur between the two inventor groups in the area of unsuccessful patents, however, with independent inventors maintaining a greater proportion of inventions through the payment of the first maintenance fee and corporate inventors maintaining a greater proportion of inventions through the payment of the second fee. As we suggested earlier, a possible reason for this might be the time needed for an independent inventor to sell his or her invention to a firm in the industry.

Appendix A

Calculating Impact

$$N_i = \sum_{grantyr_i}^{2002} citations_i \div \sum_{1971}^{2002} P_i * g_i$$

where:

N_i = impact of patent *i*

$citations_i$ = total number of times patent *i* has been cited by other patents from the year it was granted (indexed as grant year *i*) until June of 2002.

P_j = the proportion of patents cited in year *i*. P_j is computed as the number of times patents in the population are cited in year *j*, divided by the cumulative number of patents in the population in year *j*.

g_i = 1 the year is the one in which patent *i* was granted, or later
0 for years before the grant year *i*

Appendix B

Patent claims code scheme

Code		Explanation
P	**Product description**	*Which part of the racket does the claim describe?*
P1	**Entire racket**	Doesn't specify, only refers to a racket
P2	**Handle**	See drawing
P3	**Shaft**	See drawing
P4	**Throat**	See drawing
P5	**Head**	See drawing
P6	**Strings or stringing**	See drawing
P7	**Beam**	See drawing
P8	**Other**	

O	**Objective w patent/claim**	*What is the objective of the claim? If you don't find this through reading the claim/s, look in the patent abstract.*
O1	**Stronger racket**	
O2	**Less vibrations/shock/fixing tennis elbow**	
O3	**Larger sweet spot**	
O4	**Longer length of life**	
O5	**Cheaper**	
O6	**Easier to manufacture**	
O7	**Other**	

F	**Manufacturing process**	*Does the claim describe HOW:*
F1	**Extrusion**	the racket should be extruded?
F2	**Injection molding**	injection molded?
F3	**Molding, not injection**	molded?
F4	**Other**	the racket should be manufactured in any other way?

D	**Design**	*How is the racket designed?*
D11	**New element added**	
	A new part is added, such as a vibration dampener, a screw tensioning the strings, or something that is not normally found on a tennis racket (see figure 1).	
D12	**Attachment of part**	
	The claim describes **how** a part is **attached** to another. Ex: The throat piece is welded to the two parts of the handle; the leather grip is glued to the wooden handle.	
D13	**Shape**	
	The claim describes the shape of a part, such as an egg-shaped head, an oval handle, etc.	
D14	**Stringing Pattern**	
	The claim describes stringing. Ex: Strings cross in 3 directions, density of stringing.	
D15	**Beam profile**	
	The claim outlines the thickness of the racket, as seen from the side.	
D16	**Size of part**	
	The claim specifies the **absolute** size or size-range of a part. Ex: the handle is 34-38 mm thick; the head is 400mm at its widest point.	
D17	**Relative size of part**	
	The claim specifies the relative size of the part when compared to the entire racket or another part of the racket. Ex: The handle is half the total length of the racket.	
D18	**Placement of parts**	
	The claim specifies the positioning of parts relative to one another. Ex: The handle is attached at a 45 degree angle to the head.	
D19	**Other**	
	Any other claim that specifies a racket design feature but does not fit in any of the above classes.	

M	Material	*What materials are mentioned in the claim?*
M1	Wood	Any kind of wood (ash, bamboo, …) and only wood.
M2	Wood + fibre	Any kind of wood (ash, bamboo, …) in combination with glass fibre (polymers, plastics, epoxy, etc).
M3	Wood + boron or graphite	Any wood or wood/glass fibre combination AND boron or graphite.
M4	Steel	
M5	Aluminum	
M6	Aluminum with nylon throat piece	
M7	Metal alloy with titanium	Aluminum or steel combined with titanium.
M8	Metal alloy with boron, graphite, gold, etc.	Aluminum or steel combined with any of these materials.
M9	Glass fibre only	Polymers, plastics, epoxy, etc. are other names used.
M10	Glass fibre with graphite	
M11	Glass fibre with boron	
M12	Kevlar	Possibly combined with other materials, such as glass fibre or graphite.
M13	Ceramics	
M14	Foam	
M15	Other	

S	Structure or combination of materials	*Does the claim explicitly mention any of the following?*
S1	Hollow shell	
S3	Shell filled with other material	
S4	Solid material	
S5	Layering of glass fibre	
S6	Layering of other fibers (graphite, kevlar etc.)	
S7	Proportions of different materials	
S8	Other	

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Tables

Table 1

Population descriptors

	Independent Inventors	Firm-based inventors
Average number of patents	8.32	247.88
Largest number of patents	696 (George Spector)	3729 (ICI)
No patents outside dataset	65 (44%)	9 (21%)
Inventors with other tennis-related patents	35 (24%)	21 (49%)
Inventors with other sporting-goods related patents	45 (31%)	19 (44%)
Inventors with patents outside the sporting-goods arena	15 (35%)	42 (29%)
Inventors with large scope	7 (5%)	5 (12%)

Table 2

Inter-rater reliability for coding of patent claims

Code category	z-score (st. dev.)	Kappa	Interpretation (Fleiss, 1981)
Racket part(s)	71.70 (.01)	0.98	Very good agreement
Objective with claim	77.04 (.01)	0.84	Very good agreement
$Content_1$: Manufacturing process	61.55 (.02)	0.93	Very good agreement
$Content_2$: Design	82.97 (<.01)	0.74	Good agreement
$Content_3$: Materials used	55.67 (.02)	0.89	Very good agreement
$Content_4$: Structure	67.24	0.99	Very good

	(.01)		agreement

Table 3

Descriptive statistics for overall population and inventor source populations

Variable	Population	Independent Inventors	Corporate inventors	Range
Impact	0.81 (7.48)	0.14 (6.96)	2.09 (8.27)	Min –8.14 Max 42.86
Forward Citations	8.41 (7.47)	7.76 (7.00)	9.64 (8.19)	Min 0 Max 52
Patent Detail	19.76 (20.98)	17.25 (15.38)	24.5 (28.25)	Min 1 Max 192
Claims Detail	2.07 (.85)	1.93 (.77)	2.32 (.94)	Min 1 Max 5.5
Claims	9.84 (8.46)	9.34 (7.22)	10.79 (10.38)	Min 1 Max 53
Product Scope	1.6 (.80)	1.59 (.77)	1.63 (.84)	Min 1 Max 5
Scope of Innovation	1.2 (.40)	1.16 (.36)	1.28 (.45)	Min 1 Max 2

N=225 for the population-level variables, 147 for the independent inventors and 78 for the corporate inventors.

Table 4

Formal test results of technical merit

Hypothesis	Variable	Test	Result	Interpretation
1A	**Impact**	Comparison of distributions	$\chi^2(8)=23.55^{**}$ $p<.01$	The two distributions are significantly different
		Median comparison, conservative test	χ^2 (1)= 1.08 p=.30	The medians of the two groups are not different
		Two-sample Wilcoxon rank-sum (Mann-Whitney) test of medians, less conservative test	z =-1.26 p=.21	The same proportion of patents are above the median for both groups (the medians are not different)
		Proportion of distribution in lowest 20%	$\chi^2(1) = 5.89^{*}$ p = .02	Independent inventors are significantly more likely than corporate inventors to have patents with impact scores among the lowest 20% of all scores
1B	**Patent Detail**	Median comparison, conservative test	χ^2 (1)= 1.07 p= .30	The medians of the two groups are not different
		Two-sample Wilcoxon rank-sum (Mann-Whitney) test of medians, less conservative test	Z= -1.60 P= .11	The medians of the two groups are not different
		Stdev indep<Stdev Corp	Variance ratio =.29** P= .00	The standard deviations of the two groups are significantly different; the inventions of independent inventors have lower range of patent detail than those of corporate inventors
		Overall distributions	χ^2 (1)= 32.24** p< .01	The distributions of the two groups are significantly different
		Proportion of distribution in lowest 20%	χ^2 (1)= 4.41* p< .04	Independent inventors are significantly more likely than corporate inventors to have patents with detail scores in the lowest 20% of the scores
	Claims Detail	Median comparison, conservative test	χ^2 (1)= 10.70** p<.01	The medians of the two groups are significantly different
		Two-sample Wilcoxon rank-sum (Mann-Whitney) test, less conservative test	Z= -3.36** P<.01	The medians of the two groups are significantly different
		Std. dev ind. < Std. dev corp.	Variance ratio =.67** P=.02	The standard deviations of the two groups are significantly different; the inventions of independent inventors have lower range of claims detail than those of corporate inventors
1C corp. scope > ind. scope	**Scope of innovation**	Test of proportions	χ^2 (1)= 5.02* p=.02	Firms are more likely to hold patents concerning both product and process
	Product Scope	Comparison of distributions	χ^2 (4) = 3.43 p = .49	Inventions from the two groups of inventors do not come from different distributions

		Two-sample Wilcoxon rank-sum (Mann-Whitney) test	Z = -.099 P=.92	The medians of the two groups are not different
	Product Scope (entire racket versus parts)	Test of proportions	χ^2 (1)= 6.25** p=.01	Corporate inventors are significantly more likely to hold patents concerning the entire racket

Note: +: p<=.10 *: p<=.05 **: p<=.01

Table 5

Distribution of maintenance fee payments by inventor source

Patent lapses after:	Independent inventors	Corporate inventors	*Total*
Four years	31 (29%)	23 (47%)	*54* *(35%)*
Eight years	43 (41%)	14 (29%)	*57* *(37%)*
Twelve years	4 (4%)	0 (0%)	*4* *(3%)*
17 years	28 (26%)	12 (24%)	*40* *(25%)*
Total	*106*	*49*	*155*

Table 6

Commercial success test results

Hypothesis	Variable	Test	Result
2	**All fees paid**	Test of proportions	χ^2 (1)= .66 p=.42
	First fee not paid	Test of proportions	χ^2 (1)= 4.28** p=.04
	Second fee not paid	Test of proportions	χ^2 (1)= 3.85** p=.05
	Third fee not paid	Test of proportions	χ^2 (1)= .48 p=.49
	Overall distribution	Pearson chi-square	χ^2 (3)= 6.22^{+} p=.10

Note: +: p<=.10 *: p<=.05 **: p<=.01

Figures

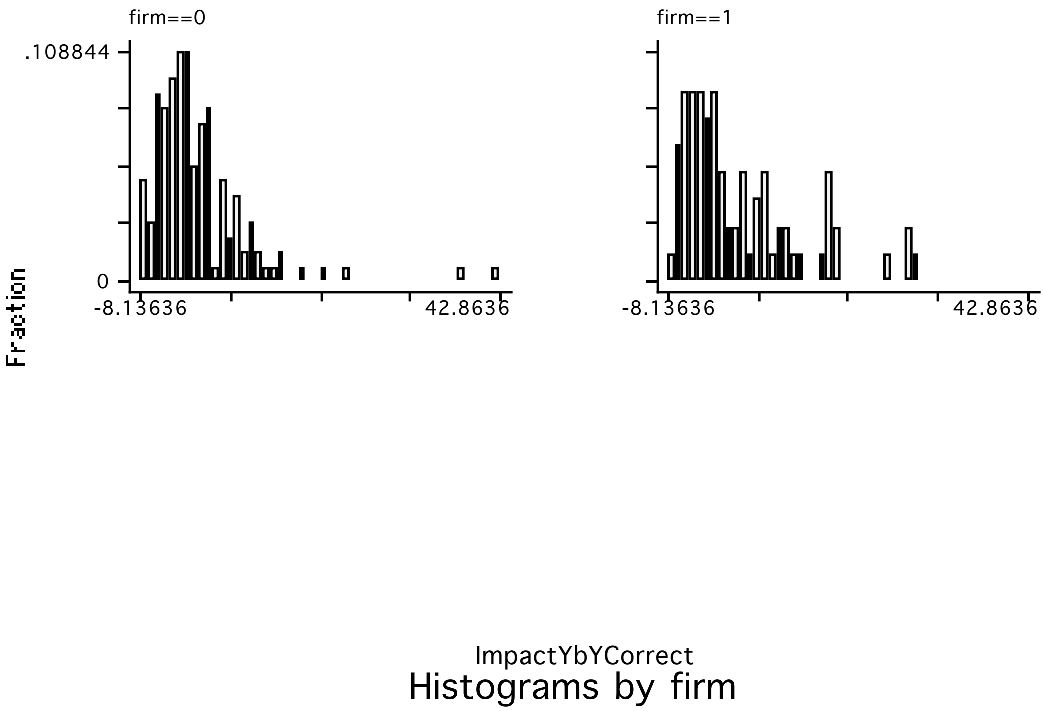

Fig. 1 The distribution of impact scores for independent and corporate inventors.

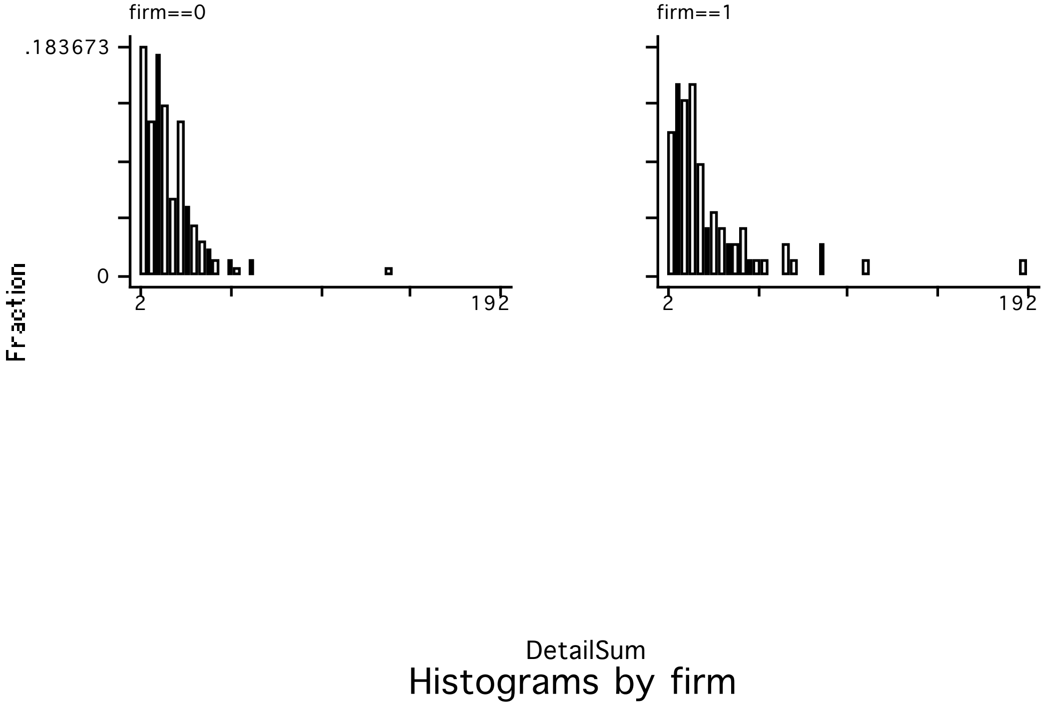

Fig. 2 Distributions of *patent detail*.

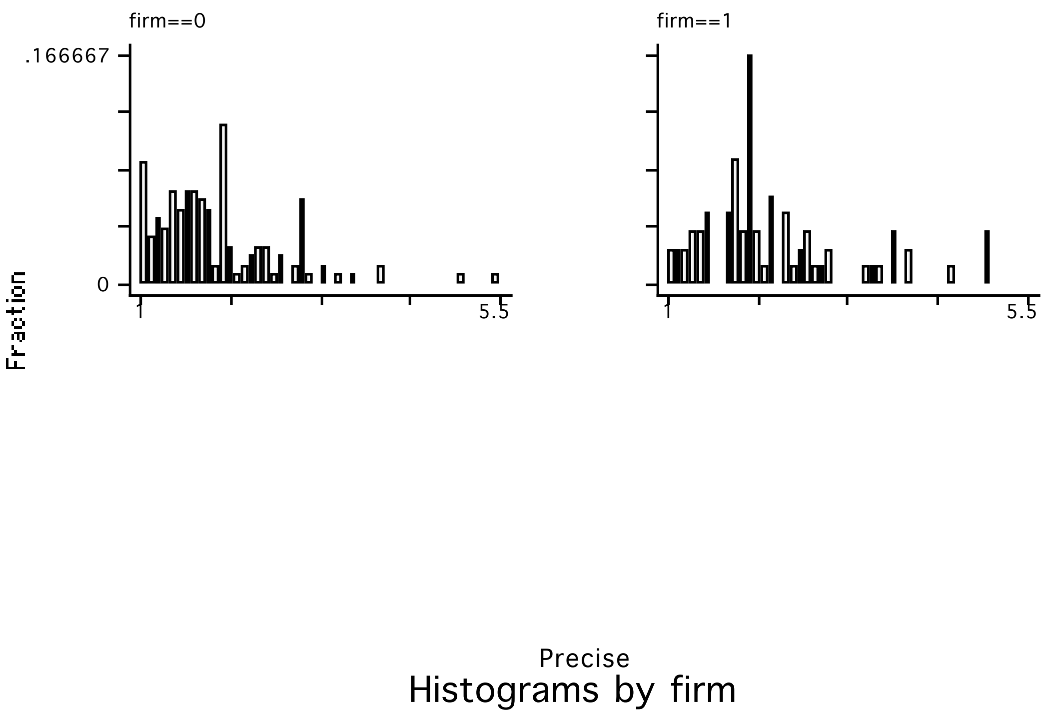

Fig. 3 The distribution of *claims detail*.

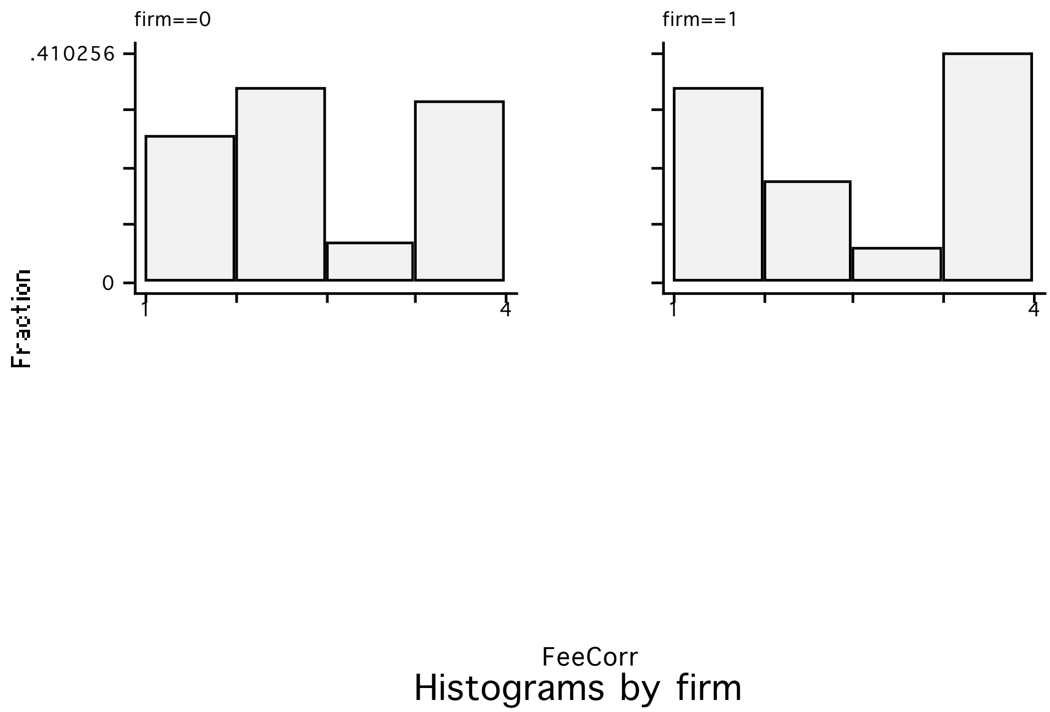

Fig. 4 The distribution of *commercial success*.