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Today's Edisons or weekend hobbyists: technical merit and success of inventions by independent inventors

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Abstract

We set out to determine if independent inventors can be considered "heroes" or "hobbyists", that is, if they produce the most or the least influential inventions in a product category. We study patented inventions by independent and firm-based inventors by comparing patents along four dimensions: Patent citation impact, detail, scope, and maintenance. Examining 225 tennis racket patents granted in the US between 1981 and 1991, we find that independent inventors are a heterogeneous group who generate inventions that are overrepresented both among the most impactful and the least impactful patents. The metrics we develop provide insight into ex ante identification of the importance of inventions.

Keywords: Independent inventors; Patents; Sources of innovation; Technology policy; Innovation indicators

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. Schrage, 2003; Prusa and Schmitz, 1991; Jewkes et al., 1969; Schumpeter, 1934; Gilfillan, 1935). There is also evidence that the development of new inventions by independent inventors is at a lower cost than similar inventions in large corporations; independent inventors have been found to bring their products to market with development costs about one-twelfth those of established firms and with gross profit margins comparable to those found in the pharmaceutical industry (Åstebro, 1998).

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But the image of iconic lone and "heroic" independent inventors—such as an Edison or a Kettering, at one point in their lives—is under threat by arguments today that their ideas are of less value than those generated by inventors within corporations. As inventions have become more industrialized, goes the argument; independent inventors have become increasingly marginal contributors to innovative activity (Rosenberg, 1994).[1] One indication of this is the decline in prominence of independent inventors in US patenting: whereas independent inventors were granted 86% of all US patents in 1910, they were granted only 15% in 1998 (USPTO, 1998).[2] Although this is a drop in absolute numbers of about only a third (35,168 patents were granted to independent inventors in 1910 versus 22,644 patents in 1998 (USPTO, 2002)), some scholars claim that patents filed by independent inventors, on aggregate, are "relatively unimportant" (Narin, 1991). Indicative of this perception, the former Commissioner of the US Patent Office, Bruce Lehman, called independent inventors "weekend hobbyists" (Chartrand, 1999).

Many studies have demonstrated that financial constraints make entrepreneurs less likely to start up companies and to succeed.[3] Indicative that such constraints also exist for independent inventors, Åstebro (1998) find that independent inventors are only about 17–25% as likely as inventors in already established firms to bring their inventions to the market. In response, one of the central issues in entrepreneurship and technology policy has been how best to support independent inventors in their efforts to commercialize their ideas (Holbrook et al., 2000).[4] If, however, the debate on the importance of the individual inventor is resolved in favor of the "hobbyist" understanding—in other words, the technical importance and potential economic value of independent inventors' ideas are considerably lower than those of firm-based inventors' ideas—the implication for entrepreneurship and technology policy is that nothing should be done with respect to the difficulties facing independent inventors in obtaining financing. In light of this debate and its policy implications, this paper evaluates the differences between the inventions of independent and corporate inventors. We explicitly study the technical content, or merit, of inventions produced by the two groups of inventors. In addition, we develop a series of metrics to aid in evaluating technical content based on textual analysis of patent claims. We elect to analyze patent claims since they provide a well-defined description of the novel part of an invention.

We chose to investigate one industry—the tennis racket industry—in a detailed manner in order to expose most effectively the differences in technical content between inventor groups. A few facts are therefore in order. The tennis racket industry is highly competitive and mature, with significant innovations by independent as well as firm-based inventors. Tennis enjoyed its greatest popularity in the US in 1978, when 35 million Americans claimed to play tennis at least once a month (Tennis Industry Association, 1992; National Sporting Goods Association, 2001). The peak year of reported racket sales, however, was 1976, when almost nine million rackets were sold in the US. At the same time as sales crested, the number of firms active in the US market also reached its apex, with 62 firms offering at least one racket model for sale (The Sporting Goods Directory, 1960–1985). In 1985, participation in the sport declined to a low of 18 million players who bought 2.7 million rackets. That participation level rebounded to 22.1 million players by 1991, but by that time, the number of firms still active in the US market

[1] Sometimes this debate is labelled Schumpeter I versus Schumpeter II since Schumpeter changed his view of the relative value of entrepreneurs and large firms as to who drives innovation (Schumpeter, 1934, 1942).

[2] 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 constraints facing these inventors.

[3] There are three different foci of this work. First is the implications of financial constraints on the choice between paid work and self-employment (Bernhardt, 1994; Blanchflower and Oswald, 1998; Evans and Jovanovic, 1989a; Evans and Leighton, 1989; Holtz-Eakin et al., 1994a). Second is the determinants of the supply of capital to start-up firms (Bates, 1990; Evans and Jovanovic, 1989b; Grown and Bates, 1991). Third is the rate of survival of small start-up firms, conditional on their access to capital (Bates, 1990; Cressy, 1996; Grown and Bates, 1991; Holtz-Eakin et al., 1994b; Åstebro and Bernhardt, 2003).

[4] For example, the NSF supported research by Gerald Udell that resulted in the Inventors Assistance Program (IAP), which assists independent inventors in assessing their inventions' likelihood of market success. The IAP has made surprisingly good predictions of great value to inventors who have not pursued dead-end projects as a result. The IAP is currently used, for example, by the Department of Energy and several universities in the US and by the Canadian Innovation Center in Canada (Åstebro and Gerchak, 2001).

had been reduced to 21. Overall, racket frame revenues have declined over the last two decades: the peak year in market value was 1979, when revenues hit US$ 392M, while in 1994, revenue was only US$ 234M (all 1994 prices).

The racket of choice at the height of tennis participation in the US had an expected life span of 1–2 years, was oval-headed, was 60–70 square inches, and was made of laminated wood (Dahlin, 1996). This racket, which replaced the solid-wood rackets that had been used for the previous 200 years, was the dominant design for about 50 years. This dominant design was challenged by several innovations in the 1960s through the 1980s that changed the competitive focus of the industry from cost reductions in manufacturing (many firms outsourced production to India and Pakistan) to product design innovations that enhanced performance along new dimensions (Utterback and Abernathy, 1975; Tushman and Anderson, 1986). By the late 1980s, the new standard racket had an increased lifespan of at least 10 years, was round or oval-headed, was 110 square inches, was made from graphite reinforced glass fiber, and had a higher per-unit price.

Challenges to the dominant racket design in the 1960s through the 1980s were focused on two main dimensions: 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 US. A "materials race" ensued after its introduction, which resulted in the development of high performance rackets made of fiberglass composites.[5] 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 1981 and the advent of the super-oversized racket before a size limit was included in the official rules of the game.[6] Another shape-based challenge was presented in 1987 with the introduction of the wide-body racket. This innovation stemmed from two papers on the physics of the tennis racket, which demonstrated that before any collision energy from the ball-string contact can be fed back into the ball by a traditional flexible thin-beam racket, the ball has long ago left the strings (Brody, 1979, 1981). Thus, a stiff racket frame like that of the wide-body racket maximizes the energy return to the ball since the strings absorb and reflect the momentum of the ball, resulting in a faster and harder ball return.

[5] Typically in these composites, graphite fibers coexist in a matrix with different combinations of ceramics and other encapsulations, creating tensions in the glass fiber and making the material stiffer.

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

2. Models and hypotheses

This paper sets out to determine if independent inventors can be considered "heroes" or "hobbyists" in the context of the tennis racket industry. We start by investigating a series of formal hypotheses on the differences between the inventions of independent and firm-based inventors along the dimensions of technical merit and commercial success. These findings have implications for the greater discussion of the independent inventor as "hero" or "hobbyist"; the characteristics we expect to observe in hobbyists will be detailed in Section 5.

2.1. Technical merit

We use three criteria for judging the technical merit of an invention—which, in a perfect world without constraints on access to financial resources, should be positively linked to an invention's success in the marketplace. First is the "technical importance" of an invention, or its influence on ensuing innovations in the same product category. Second is the "level of detail" of an invention, or how well thought-out the invention is as communicated to observers (this metric is an indicator of the realism and completeness of an invention). Third is the "scope," or extent, of an invention (e.g. whether the invention consists of an entire system or one small part of a system). For each of these aspects of invention, we hypothesize that different sources of invention will be dominant.

2.1.1. Technical importance

Many scholars and practitioners distinguish between inventions by their technical importance (e.g. Tushman and Anderson, 1986; Henderson, 1993;

Henderson and Clark, 1990; Ettlie et al., 1984). In light of the debate over the importance of independent inventors, we expect that the technical importance 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 inventions of great technical importance than are firm-based inventors.

This 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, 1934; Reinganum, 1983; Henderson and Clark, 1990). In addition, the typical work experience of the independent inventor—who often has a background in an industry different than the industry being invented in—also lends weight to the novelty, and hence, technical importance, of his or her inventions (von Hippel, 1988).

But the above argument can be flipped: While freedom from an industry's preconceived notions may lead in some cases to novel new inventions, in other cases, the absence of the intellectual support mechanisms of the firm may lead to more marginal inventions. These support mechanisms are likely to provide important industry-specific knowledge to firm-based inventors, such as the performance dimensions important to users, more effective racket design features, etc. Based on our experience with the tennis racket industry, we believe it is possible that both views of the independent inventor—hero and hobbyist—will find support in this industry (Hughes, 1989; Lamberton, 1971; Petroski, 1992; Narin, 1994a; USPTO, 1998; Chartrand, 1999). Thus, we hypothesize that:

Hypothesis 1A. Independent inventors will be over-represented in both the technically important and technically unimportant invention populations.

2.1.2. Level of detail

It is likely that there will be variability among inventions in terms of how well thought-out or detailed they are. We believe that less-detailed inventions will be linked in part to the varying resources available to independent and corporate inventors, particularly as these resources affect the sources of information accessible to an inventor. For example, 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 customer relations as additional sources of inspiration for research (von Hippel, 1988; Christensen and Rosenbloom, 1995). 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. Thus, we hypothesize that:

Hypothesis 1B. Independent inventors will have less detailed inventions than corporate inventors.

2.1.3. 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 be influenced by the cycle of new model releases to work on the development of entirely 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 product 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

Previous studies, such as Åstebro (1998), indicate a lower commercialization rate for independent inventors than for corporate inventors. For consistency, we need to reestablish these results with the inventions evaluated for technical merit in the tennis racket industry. Based on previous studies, therefore, we hypothesize that:

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

3. Data sources and methodology

3.1. Data sources

The data source we use to evaluate the differences in hobbyist characteristics between the inventions created by independent and corporate inventors is a subset of US 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 technical importance of an invention associated with a patent (Taylor, 2001; Harhoff et al., 1999; Lanjouw and Schankerman, 1999; Albert et al., 1991; Narin, 1994; Trajtenberg, 1990). We use patent citations as the basis of our "impact" metric of technical importance, which we use to evaluate Hypothesis 1A.

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. In particular, the claims section of the patent outlines the content of the invention and defines the monopoly rights granted to the inventor. 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 and Frame, 1994).

A third advantage of the use of patents is that patent analysis can provide insight into the commercial success of an invention in the marketplace. 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 (cf. Taylor, 2001; Lanjouw et al., 1998; Pakes and Schankerman, 1984; Pakes and Simpson, 1989). These fees, which increase over time, have been levied on patents filed on and after 12 December 1980. They are due at 3.5, 7.5 and 11.5 years from the grant date at rates of US$ 445, US$ 1025, and US$ 1575, respectively, to ensure the full monopoly rights of the patent (USPTO, 2000).[7] Research utilizing renewal fee information studies the period of time over which these fees are paid in order to assess the private economic value of a patent to its owner. In order to track the commercial success of a relatively large sample of patents, we choose to focus on US 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.

The tennis racket industry has several patent characteristics that are helpful to this study. First, for the last 25 years, the industry has had a high propensity to patent, according to both the industry association and one of the leading firms (Chen, 1998; Patterson, 1996).[8] Second, the tennis racket has a long history of patenting activity that includes a significant number of patents by independent inventors, and both independent and firm inventors hold large enough patent pools to perform statistical tests. Third, there are indications of similar patenting behavior between firms and independent inventors: Both groups patent as soon as they believe they have a patentable invention and a potential market (Chen, 1998),[9] both groups use patent attorneys

[7] Fees stated are for small entities in 2003 in US$; both firms and independent inventors are subject to the payment of these fees in order to avoid a suspension in monopoly rights. In other words, a granted patent will have a minimum of 4 years protection, but will then lapse if the first maintenance fee—at 3.5 years—is not paid. If this fee is paid, patent validity will extend an additional 4 years and then lapse if the second fee, due at 7.5 years, is not paid. If this fee is paid, the patent will lapse at 12 years after the initial grant date unless another fee has is paid at that point in order to ensure the full protection period of 17 years.

[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 et al., 2000; Brouwe and Kleinknech, 1999; Cohen and Levin, 1989).

[9] A large number of infringement lawsuits have occurred in this industry, which implies that patenting in this technology area is strong enough to serve as an important protection for intellectual property.

or agents to the same extent,[10] and the strategy of one-invention-one-patent seems to dominate for both firm and independent inventors.

Fourth, the concordance between the SIC code and the patent classification for tennis rackets is close to perfect; this reduces the possibility for error in understanding patenting behavior in the industry.

Adding to the degree of sophistication we can attribute to independent inventors in the tennis racket industry are a number of patenting statistics from both inside and outside our database. Whereas our tennis racket patent dataset consists of 225 US patents granted between 1981 and 1991, 147 of these patents (65%) were granted to independent inventors and 78 (35%) were granted to firm-based inventors. Looking at the patenting activity of these groups in the overall USPTO dataset, we see that 55% of independent inventors and 79% of firms typically have patents in areas other than tennis rackets. When we look at USPTO patenting trends overall for both independent inventors and firms, we find that the frequency distributions assigned to both groups are skewed, although the degree of skewness is different between them. The average number of patents held by independent inventors with patents in our dataset is 10, although the median number of patents held is only 2 (a difference of five to one). Similarly, the average number of patents held by firms with patents in our dataset is 248, although the median number of patents held is only thirteen (a difference of 19 to 1). Finally, we find that a surprisingly high percentage of independent inventors in our dataset hold multiple patents (59%), with 19% restricted to holding only non-sporting goods-related patents besides the patents they hold in our dataset. Note that in many cases these independent inventors will patent in other technology areas under the name of a firm assignee, thus indicating that they have professional technical expertise in other areas. We also discovered that foreign independent inventors are well represented in our data: 40% of independent inventors list a non-US address. For firms, this number is higher; 50% of all corporately owned tennis patents in this time period belong to non-US firms.

[10] Firms in the tennis racket industry are typically too small to have their own in-house legal teams and seem to draw attorneys from the same pool used by independent inventors.

3.2. Methodology

3.2.1. Measures

Our construction of measures for *impact*, *level of detail*, *scope*, and *success* is the most important element of the methodology for this study. *Impact* is based on the number of times a given patent has been cited as prior art in subsequent tennis racket patents granted up to June 2002 (so-called forward citations, see Table 1 for data). We weight the citation-based impact score to control for annual variations in patenting frequency and to control for the fact that older patents have a greater opportunity for citation by subsequent patents than do younger ones by using the formula:

$$N_i = \sum_{j \geq k}^{2002} \left(c_{ij} - \frac{x_j}{y_j} \right)$$

In this formula: N_i is the impact of patent i; k = [1981, 1991] the grant year for patent i; c_{ij} the number of citations to patent i in year $j \geq k$; x_j the number of times all patents in the population of tennis rackets issued after 1971—the earliest point we can get systematic citation data—are cited in year j; and y_j the cumulative number of patents in the population of tennis rackets in year j (counting from 1971). The formula allows us to correct for increases in patent rates and variations in the likelihood of being cited by comparing the probability that a given patent will be cited to the probability that any tennis racket patent will be cited in a given year.[11]

Given that self-citation tends to drive up citation rates for a patent, we examine the citation records for patentees with more than one patent in our database (Hall et al., 2001). We find the highest self-citation rate for Dunlop's patent number 4,747,598, where four of the 32 cited patents, or 12.5%, are other Dunlop patents. The second highest self-citation rate is found for Rossignol (patent number 4,875,679), where one of 19 cited patents, or 5.2%, are self-cited patents. For other firms, the rate is zero.

[11] While we sample patents from 1981 to 1991 period for our main analyses, we use all tennis racket data available to us to make the best possible assessment of likelihood of being cited, which means including patents for the entire 1971–2002 period when determining the values of x_j and y_j.

Table 1
Descriptive statistics for technical merit measures: means, standard deviations (in parentheses) and range

Variable	Population	Independent inventors	Corporate inventors	Range
Citation impact	0.81 (7.48)	0.14 (6.96)	2.09 (8.27)	−8.14, 42.86
Forward citations	8.41 (7.47)	7.76 (7.00)	9.64 (8.19)	0, 52
Patent detail	19.76 (20.98)	17.25 (15.38)	24.5 (28.25)	1, 192
Claims detail	2.07 (0.85)	1.93 (0.77)	2.32 (0.94)	1, 5.5
Claims	9.84 (8.46)	9.34 (7.22)	10.79 (10.38)	1, 53
Product scope	1.6 (0.80)	1.59 (0.77)	1.63 (0.84)	1, 5
Scope of innovation	1.2 (0.40)	1.16 (0.36)	1.28 (0.45)	1, 2

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

Corrections for self-citations make no difference to our distributions.[12]

To measure the *level of detail* and *scope* of patents, we perform content analysis on the 2215 claims of the 225 tennis racket patents in the population. This content analysis is based on a code scheme we have developed to capture three categories of claim information: What parts of the racket the claim concerns (e.g. the entire frame, the handle, the throat, the strings, etc.), the technical objective (e.g. to make a stronger racket or a larger sweet spot, enhance the frame durability, etc.), and the innovative content (see Appendix A for the code scheme).

The innovative content category consists of information on two hierarchical levels. At the first level, the characteristics of each claim are 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 is more specific; we have subdivided each of the 4 first-level categories into between 5 and 16 sub-categories (see Appendix A for the complete code scheme). Each claim can be coded in multiple categories. As an example, the first claim (of nine) 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.

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 have assigned nine codes for product parts for this patent (one for each claim). All of these codes are in one subcategory since they pertain to the entire frame of the racket. No manufacturing codes are given, nor are materials or material structures discussed. Nine design codes are 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 have assessed all claims from the 225 patents according to this scheme. Both coders have first coded the same twenty percent of the patents for

[12] This lack of self-citation is probably due to an inability to fence off areas of intellectual property rights in this particular technology (Cohen et al., 2000).

validation purposes. Inter-rater reliability is determined using Cohen's kappa. Cohen's kappa measures the likelihood of two (or more) coders having achieved agreement after controlling for the chance likelihood that they would agree (Cohen, 1960). According to Fleiss (1981), a score above 0.75 shows very good agreement between coders. The racket part of the claim, the technical objective of the claim, and three of the four descriptive categories of the claim (manufacturing process, materials used, and structure) all have kappa scores between 0.84 and 0.99 with a mean of 0.93. Only the descriptive category of design has a score below 0.75, although it is still an acceptably high 0.74.

To construct the *level of detail* measure, we have 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 is defined as the sum of all the content codes the patent has 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 divide *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 (−0.08), indicating that these are two independent measures and that a low level of detail in a claim is not compensated for by adding more claims.

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 narrower scope than a patent that covers multiple parts, such as the throat piece and the handle 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.

Finally, the economic significance of inventions is complicated to assess, even if we are only concerned with the significance of the inventing firm or individual (Tether, 1998). For our measure of *success*, we use an increasingly common measure of a patent's value to an inventing unit: the number of patent maintenance or renewal fees paid by a patent assignee. A number of studies have investigated the relationship between renewal data and the value of a patent to the patent holder (Pakes, 1986; Lanjouw, Pakes and Putnam, 1998; Pakes and Simpson, 1989; Harhoff et al., 1997). This growing body of literature is beginning to enable more nuanced interpretations of the results of analyses using renewal fee payments. This fact, as well as the ready availability of data, makes renewal fees an increasingly attractive proxy measure of commercial success.

As with much evidence about inventive activity, studies of patent renewal fees indicate that only a small proportion of patents is highly valuable (e.g. Lanjouw, et al., 1998). Given the skewness of the patent value distribution, we treat commercial *success* as a binary measure in which a *successful* patent has had all three 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. This gives us a conservative estimate of success since it is possible that short product life cycles might not warrant full-term protection of even valuable inventions. The *unsuccessful* patent is distinguished by the length of time that the patent owner chooses to maintain it.[13]

3.3. Tests

There are noted trends in patent data in which a small number of patents account for the majority of commercial returns in a class and in which a small number of assignees have a disproportionate share of patents when compared to most assignees (Scherer and Harhoff, 2000). In our case, the skewed nature of patent data is reflected 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. Indeed, none of the variables we used to test our hypotheses exhibit the characteristics of a normal distribution. As a result, since many of our variables are counts and we

[13] Recall that patents filed in 1981 or later are eligible for the payment of maintenance fees. All 225 of our tennis racket patents were granted between 1981 and 1991 but some were filed prior to 1981. This means that some are not exposed to renewal fees while the ones that are, are eligible for all three fees.

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 Pearson'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 skewness (Sprent, 1993; StataCorp, 2001). See Table 1 for summary statistics for the data.

4. Results

4.1. Technical merit

4.1.1. Impact

Hypothesis 1A predicts that independent inventors will be over-represented in both the technically important and technically unimportant invention populations; this should be indicated by larger right- and left-hand tails of the citation-based patent impact distribution. A Pearson's χ^2-test of the impact distributions by inventor source tells us that the distributions are significantly different (see Table 2 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), so we find that the differences between the two distributions are indeed in the tails.

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. In the high-impact range, 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 for a formal test. The distributions are denser in the low-impact range, however, and formal tests demonstrate a significant difference in the proportions of independent and corporate patents that inhabit the lower 20% of the impact distribution. 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.

4.1.2. Patent detail and claims detail

Hypothesis 1B states that independent inventors will patent with a lower level of detail than corporate inventors, as measured by *patent detail* and *claims detail*. Indeed, we find this to be true for both metrics as well as a combination of the two metrics. Analysis of the *patent detail*—the summation of the content codes for a patent—of independent and corporate inventor patents shows that although the overall distributions and variances are significantly different, the medians do not significantly differ. The corporate inventor distribution has a higher variance, mainly because of a longer tail in the high end of the distribution, while the independent inventor distribution has a larger proportion of patents in the low end of the distribution. This difference is significant for the proportion of patents in the bottom 20% of the distributions; in this range falls 85% of independent inventions and 74% of corporate inventions. Analysis of the *claims detail*—the *patent detail* divided by the number of patent claims, a metric that corrects for the sometimes strategic choice of how many claims to include in a patent—also supports the hypothesis that independent inventors have less detailed patents. 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 2 for test results). In addition, 10% of independent inventor patents versus only 4% of firm-based patents exhibit scores in the bottom 25% for the metric of combined *patent detail* and *claims detail* scores.

4.1.3. Scope

Hypothesis 1C states that independent inventors will generate inventions of less scope than corporate inventors, as measured by *product scope* and *scope of innovation*. We find that our results differ depending on the measure of scope we use. Analysis of the *scope of innovation* of independent and corporate inventor patents—the type of innovation the patent addresses—shows that firm-based inventors are more likely to file patents concerning process innovations, as well as patents that outline a combination of new product design and an associated manufacturing process. On the other hand, analysis of the *product scope*—the

Table 2
Formal test results of technical merit

Hypothesis	Variable	Test	Result	Interpretation
1A	Citation impact	Comparison of distributions	χ^2 (8) = 23.55**, P < 0.01	The two distributions are significantly different
		Median comparison, conservative test	χ^2 (1) = 1.08, P = 0.30	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 = 0.21	The same proportion of patents are above the median for both groups (the medians are not different)
		Proportion of distribution in lowest 20%	χ^2 (1) = 5.89*, P = 0.02	Independent inventors are significantly more likely than corporate inventors to have patents with citation impact scores among the lowest 20% of all scores
1B	Patent detail	Median comparison, conservative test	χ^2 (1) = 1.07, P = 0.30	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 = 0.11	The medians of the two groups are not different
		S.D. ind. < S.D. Corp.	Variance ratio = 0.29**, P = 0.00	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 < 0.01	The distributions of the two groups are significantly different
		Proportion of distribution in lowest 20%	χ^2 (1) = 4.41*, P < 0.04	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 < 0.01	The medians of the two groups are significantly different
		Two-sample Wilcoxon rank-sum (Mann–Whitney) test, less conservative test	$z = -3.36$**, P < 0.01	The medians of the two groups are significantly different
		S.D. ind. < S.D. corp.	Variance ratio = 0.67**, P = 0.02	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	Scope of innovation	Test of proportions	χ^2 (1) = 5.02*, P = 0.02	Firms are more likely to hold patents concerning both product and process
	Product scope (number of racket parts)	Comparison of distributions	χ^2 (4) = 3.43, P = 0.49	Inventions from the two groups of inventors do not come from different distributions
		Two-sample Wilcoxon rank-sum (Mann–Whitney) test	$z = -0.099$, P = 0.92	The medians of the two groups are not different
	Product scope (entire racket)	Test of proportions	χ^2 (1) = 6.25**, P = 0.01	Corporate inventors are significantly more likely to hold patents concerning the entire racket

Note: (+) $P \leq 0.10$; (*) $P \leq 0.05$; (**) $P \leq 0.01$.

number of parts of a racket the patent covers—shows no significant difference in the patented inventions of the two groups of inventors, although we did find that independent inventors are less likely to patent inventions concerning the overall racket than are corporate inventors (see Table 2 for test results). When we combine the two scope metrics and isolate the patents with the lowest value for both, we find that 43% of patents by independent inventors have combined low scores compared to 26% of patents by firm-based inventors.

4.2. Commercial success

Hypothesis 2 states that independent inventors are likely to have less commercially successful inventions than corporate inventors as measured by the maintenance of patents over time. We do not find direct support for this hypothesis; inventor source does not appear to affect the proportion of *successful* tennis racket patents as defined by full maintenance (only 25% are thus *successful*). Among *unsuccessful* patents, however, differences between independent and corporate inventors are evident. Table 3 displays the proportions of *unsuccessful* patents by the two inventor sources according to the period of maintenance: 4, 8, and 12 years. Independent inventors are significantly more likely to maintain their patents beyond the 4-year period than are corporate inventors (71% versus 57%). The opposite is true after the 8-year period, however, when 59% of still-valid independent patents are renewed in contrast to 71% of still-valid corporate patents. After the 12-year period, these differences in maintenance fee behavior diminish. We know that in the tennis racket industry patents are important to independent inventors because they need them in order to market their inventions externally (Chen, 1998). This process is likely to be less efficient than the process followed by firms when deciding whether to bring patented technology into production. We discuss the finding that independent inventors are significantly more likely to maintain their patents beyond 4 years but less than 8 years further in Section 5.

5. Discussion

We examined differences between the inventions of independent and firm-based inventors in the tennis racket industry along the dimensions of technical merit and commercial success. In this section, we briefly reiterate these findings and discuss their implications.

5.1. Heroes or hobbyists?

Our analysis give credence to both the view of the independent inventor as "hero" and as "hobbyist" while underscoring the large uncertainty associated with the value of innovation by independent inventors. We use three criteria for judging the technical merit of inventions: technical importance (or impact), detail and scope. We demonstrate that independent inventors are able to produce more high-quality inventions at the same time as they dominate the low-quality inventions in a product category. Analyzing patent claims, we looked for evidence of differences in technical merit between the two inventor groups, hypothesizing that independent inventors would have less *detailed* patents of lower *scope*. We did find that firm patents are more detailed both on the patent and the claims level-of-analysis and with respect to scope, we find that firm-based inventors have patents with higher scope than independent inventors as measured by one of two scope metrics; not surprisingly we find that firm-based inventors are more likely to file patents that contain specifications concerning process innovations as well as patents that outline a combination of new product design. A less anticipated finding is that for a second metric, *product scope*, which details the number of parts of a racket covered by a patent, there is no significant difference between firm-based and independent inventors. However, when converting product scope into a binary measure of whether the patent is about the entire racket or just a part of it, we find that independent inventors are less likely to patent inventions concerning the overall racket.

Actions related to identifying heroes and hobbyists ex ante rather than ex post may be of interest, for example to venture capitalists. Our results show that this can be done. First, we investigated whether two technical merit criteria—level of detail and scope—relate to the technical importance of a patent as measured by our citation-based impact metric. We find zero-correlations between the detail measures and impact, but detected a significant and weak correlation ($r = 0.15$, $P < 0.05$) between *invention scope* (if the patent

Table 3
Commercial success (data and test results)

Hypothesis	Variable	Independent inventors	Corporate inventors	Comparison of groups
2	Number of granted patents requiring fee payments[a]	106	49	
	First fee not paid, patent upheld for 4 years	31 (29%)	23 (47%)	χ^2 (1) = 4.28*
	Second fee not paid, patent upheld for 8 years	43 (41%)	14 (29%)	χ^2 (1) = 3.85**
	Third fee not paid, patent upheld for 12 years	4 (4%)	0 (0%)	χ^2 (1) = 0.49
	All fees paid, patent upheld for maximum 17 years	28 (26%)	12 (25%)	χ^2 (1) = 0.07
	Overall distribution: 4,8,12 and 17 year patent life span	31, 43, 4, 28	23, 14, 0, 12	χ^2 (3) = 6.22$^+$

Note: (+) $P \leq 0.10$; (*) $P \leq 0.05$; (**) $P \leq 0.01$.

[a] We sampled patents granted from 1981. However, patents filed prior to 1981 were not eligible for fee payments subsequent to granting, why this analysis involves 155 patents rather than 225.

is about both product and process versus just one of the two) and impact. We also found a weak negative correlation between impact and whether the patent is about the entire racket ($r = -0.16$, $P < 0.05$). Taking the analysis one step further, we find that patents with low *combined* scores on level of detail as well as low *combined* scope scores never appear in the top 50% of patents according to their future citation impact.

We also compare the commercial success of independent and firm-based inventors—as measured by the maintenance of patent rights—and find that neither group of inventors holds a disproportionate share of fully maintained patents. Having said that, independent inventors are significantly more likely to maintain their patents beyond the initial renewal period than are firm-based inventors. One explanation for this finding is that in the tennis racket industry, the market for inventions is relatively strong, which has lead to a dominant strategy of independent inventors to patent their inventions and then market them to existing firms that possess the complementary assets needed for market access (Chen, 1998; Schomo, 2003). Finding and negotiating a license agreement for an invention may be a lengthy process, suggesting why an independent inventor will face a longer period of uncertainty about the value of his or her patent, being willing to maintain the patent one period longer than a firm.

5.2. *How common is the hobbyist?*

While our overall finding is that independent inventors are a heterogeneous group, containing both heroes and hobbyists, we want to explore the prevalence of hobbyists in the independent inventor population. To do this we need to define more precisely what is meant with the term hobbyist. We argue a hobbyist is an inventor: (1) whose invention has a low level of influence on other inventions; (2) who is a non-habitual, that is infrequent, inventor; and (3) who exhibits susceptibility to intangible rewards that appear to contradict economic rationality. Since our earlier finding—that independent inventors hold a disproportionate share of both high- and low-impact patents—indicates that the first condition is met for a subset of independent inventors—the rest of this section will focus on the other two conditions.

In investigating whether independent inventors in our dataset meet the second hobbyist characteristic of patenting with low frequency, we find that a significant minority (65, or 44%) holds only one patent, and therefore can be considered *non-habitual* inventors. We find that 52% of patents in the bottom 10% of the impact range are held by *non-habitual* inventors (who have a likelihood of 0.49 to hold such low-impact patents). In comparison, inventors who hold more than one patent are less likely to end up in the low-impact range of patents (their likelihood is 0.26 to hold such a low-impact patent). Also of interest, we find that the average independent inventor in our sample holds 8.32 patents (while the average firm in our sample holds almost 248 patents), with the most prolific independent inventor holding 696 patents that cover a large number of product categories. A number of independent inventors, 15 (35%), also hold patents outside sporting good industries, giving a strong indication that the 44% non-habitual inventors are balanced by habitual inventors spanning multiple technology areas. In fact, in our sample, we find a larger fraction of independent inventors than firms inventing in as well as outside sporting goods.

Finally, in investigating whether independent inventors in our dataset meet the third hobbyist characteristic of exhibiting susceptibility to intangible rewards that appear to contradict economic rationality, we first have to determine two conditions that we believe indicate such an inventor. Rational behavior can be inferred if inventors either fully maintain impactful patents or do not fully maintain unimportant patents. Expanding that logic, we argue that inventors might be less rational if they chose either to NOT maintain technically important patents OR if they chose to maintain technically unimportant patents. In the first scenario, the hobbyist inventor does not fully maintain the patent rights for a technically important invention; we do not find this to be true since the correlation between impact and length of maintenance is positive ($r = 0.23$, $P < 0.01$). However, we do find that *firm-based* inventors exhibit zero correlation between the two indicators of impact and length of maintenance ($r = -0.09$, $P > 0.1$).[14] In the second scenario, the hobbyist inventor fully maintains the patent rights for a trivial invention. We focus on the population of *non-habitual* inventors to test this, as these hobbyists might be more likely to want to maintain their sole patent for reasons other than expected financial rewards. However, analysis of variance on the patent maintenance periods of *non-habitual* patent holders versus others show no significant differences between the groups, hence, we do not find support for the idea that non-habitual inventors use different criteria for maintaining their patents than other inventors.

In conclusion, although some of our findings support the "hobbyist" understanding of independent inventors, the preponderance of evidence we have gathered does not. The technical importance of patents held by independent inventors is both very high and very low; a minority of independent inventors in this dataset are *non-habitual* patentees (although this minority is sizable and in about half the cases corresponds with low-impact patents); and independent inventors actually seem less susceptible to non-economic incentives than do firm-based inventors. As our analyses of the complete patent portfolios of all our independent inventors (as well as firms) demonstrated, inventors that show up as independent inventors in tennis rackets often are listed as inventors on patents owned by firms in other technologies. Thus, many independent inventors are professional engineers and scientists with working knowledge of invention and the patent system.

Thus, independent inventors in the tennis racket industry must be considered a heterogeneous group of both hobbyists and heroes with professional technical expertise in other areas; policymakers should consider them such.

At the same time as many independent inventors are producing worthwhile inventions, the "hobbyist" part of our findings suggests that independent inventors associated with technically unimportant patents may need to be more discouraged to patent. A simple policy would be to increase patent fees for independent inventors (who now in the US pay half the fees of large firms). However, this policy will also strike against the hero inventors, the overall impact of the policy depending on the price elasticity of both hobbyist and hero inventors as well as they potential lost opportunity associated with hero inventions not being patented. Another alternative would be to selectively advice inventors filing patents for unimportant inventions to focus their resources on more worthwhile pursuits, advice that has been found to be socially effective (Åstebro and Bernhardt, 1999).

This study provides some insight into how to filter out independent inventors with less promising inventions through our content-based patent metrics. We believe these metrics have the potential to assist in quick assessments of invention in other technology areas. While constructing appropriate coding schemes is time-consuming, we believe that experts in many technology areas could construct similar schemes by focusing on significant functional aspects of their technology of interest. A follow-up study on a technology area with different characteristics—such as a complex

[14] We can think of two explanations in addition to that of economic irrationality that might explain this lack of correlation between impact and maintenance but ruled both out. First, one could imagine that citation impact might be artificially low for a firm-owned patent if later inventors do not enter the firm's patent space, suggesting that the firm has fenced off an area, making it unattractive for competitors to enter. However, we see no major differences between the citation impact of patents held by independent and firm-based inventors other than at the tails of the distribution, ruling out this explanation. Second, one could imagine a firm maintaining a low-impact patent for strategic reasons, such as excluding others from having free access to the technology, but we do not find this explanation convincing since the proportions of successful patents held by independent and firm-based inventors are the same.

process technology rather than the consumer product technology analyzed here—would be necessary to address this. We expect there to be a lower proportion of independent inventors in such a technology due to barriers to independent invention. However, those individual inventors that do file for patents are likely to be well informed due to the larger stock of knowledge necessary to successfully generate an idea and obtain a patent.

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Appendix A. 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?

Code	Explanation
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 Fig. 1)
D12 Attachment of part	The claim describes how a part is attached to another. Example: 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. Example: strings cross in three 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. Example: the handle is 34–38 mm thick; the head is 400 mm 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. Example: 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. Example: 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-I-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	

Code	Explanation
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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