AN EAR FOR YOUR QUOTES

PATENT CITATIONS AND THE SIZE OF PATENTED INVENTIONS, EVIDENCE FROM HYBRID CORN

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This paper links applications for utility patents between 1985 and 2005 with field trial data on improvements in yields to examine whether citations are a good measure for the size of the "inventive step," measured as improvements in yield. These data indicate that a large and robust correlation between citations and the size of improvements. In the most conservative estimates, a 10 percent increase in yields is associated with 1.7 additional citations, implying a 24 percent increase. A small number of highly cited patents appear to be cited mostly to establish the patentability of corn hybrids. Estimates that exclude these patents indicate that a 10 percent in yields is associated with 1.2 additional citations, implying a 34 percent increase. Analyses of claims and renewal data as alternative measures of patent value suggest that citations are in fact the most informative measure for the size of patented inventions.

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A common concern with using patent data as a measure of invention is that "inventions that are patented differ greatly in 'quality,' in the magnitude of inventive output associated with them" (Griliches 1990, p. 1669).[1] For example, Simon Kuznets (1962, p. 37) observes that "the main difficulty with patent statistics is, of course, the enormous range in the magnitude of the inventions covered." Counts of later patents that cite a patent as relevant prior art have emerged as the standard measure of patent quality, fuelled in part by the availability of electronic data in the NBER patent citations data (Hall, Jaffe, and Trajtenberg 2001), and more recently, in the Google/USPTO historical patent data base.[2]

To establish that citations are a useful proxy for the magnitude of inventions, previous studies have compared counts of citations to more valuable patents with counts of citations to less valuable patents (e.g., Carpenter, Narin, and Wolf 1981).[3] Most prominently, Trajtenberg (1990) established that citations counts are positively correlated with the estimated social surplus of 456 improvements in CAT scanners. Citations are also positively correlated with changes in the stock market value of U.S. firms (Hall, Jaffe, and Trajtenberg 2005), and with inventors' reported valuation of their patents (e.g., Harhoff, Narin, Scherer, and Vopel 1999).

Recent empirical research, however, indicates that citations may be a noisy and biased measure for the size of patented inventions, and proposed alternative measures. For example, 63 percent of all citations in patents issued between January 2001 and August 2003 were added by patent examiners (Alcazer and Gittelman 2007, p. 775), who may be more likely to add citations to a small set of "favorite"

[1] Also see Griliches (1998), pp. 296, 308.

[2] E.g., Kortum and Lerner 2000, Sørensen and Stuart 2000; Qian 2007; Kerr 2010; Lampe and Moser 2010; Belanzon 2012). Lampe and Moser (2012) extend existing data sets of patent citations backwards to begin in the 1920 (using the full text of patent documents in the Google/USPTO historical data set. Historical analyses of innovation have used prizes to exceptionally innovative exhibits at world's fairs as an alternative control for the quality of innovations (Moser 2005, 2012). Prize data, however, cannot quantify the size of patented inventions (beyond distinctions in gold, silver, and bronze), and are not available for most contemporary settings. Today, *All-American Seed Selection Prizes* are awarded to garden varieties for sweet corn, but not to field corn, which is the subject of most commercial R&D.

[3] Carpenter, Narin and Woolf (1981) show that 100 "important" patents between 1969 and 1974 – which the authors define by matching patents with "the 100 most significant technical products" selected by the journal *Industrial and Research Development* in 1969 and 1970 - were cited by 494 later patents, while 102 control patents that had been issued in the same year were cited by 208 later patents. Albert, Avery, Narin, and McAllister (2001) find that – in a data set of 77 patents selected from 129 USPTO patents by Eastman Kodak for silver halide technologies in 1982 and 1983 – a group of highly cited patents (with more than 10 citations) were rated far more highly than other innovations by 20 of Eastman Kodak's researchers were highly correlated.

patents that they know well, and inadvertently miss citations if they are less familiar with the subject matter (Cockburn, Kortum and Stern 2002), for example in financial methods (Lerner 2002) or biological patents, which have only recently become subject of utility patents. These issues are particularly severe in periods when the workload of examiners is high and examiners cannot invest the 15 to 18 hours required for a thorough examination (Merill et al. 2004, p. 51; Lemley 2001).[4] Most critically, however, citations may be a biased measure for the size of innovations if patentees may withhold citations strategically and if the size of the patented invention helps determine the citations behavior of inventors (Sampat 2010; Lampe 2012).

This paper uses field trial data on improvements in yields hybrid corn to examine the link between citations and the size of patented inventions.[5] U.S. breeders began to hybridize corn seeds after 1908, when plant scientists George H. Shull and Edward M. East discovered that an experimental cross between two inbred corn plants produced more corn than varieties that had been allowed to pollinate in the field. In 1923, Henry A. Wallace, founder of the Pioneer Seed Company, began to commercialize *Copper Cross*, which became the first hybrid to win a gold medal at the prominent Iowa Corn Yield Contests.[6] Improvements in yield helped fuel a rapid shift from inbred to hybrid corn. In 1933, hybrid seed was planted on less than one percent of U.S. corn acreage. By 1939, its share had risen to almost half. By 1960, nearly all U.S. corn acreage was hybrid seed (Griliches 1957, 1960; Olmstead and Rhode 2008, pp. 64-67).

Hybrid corn became subject to U.S. utility patents in 1985, when the United States Patent and Trademark Office (USPTO) decided that seeds, plants, and plant cultures were patentable (*Ex parte*

[4] In a data set of 182 U.S. patents for which the Court of Appeals for the Federal Circuit (CAFC) ruled on validity between 1997 and 2000, missing citations were the most common cause for invalidation (Cockburn, Kortum, and Stern 2002).

[5] Field (rather than garden variety) corn accounts for more than 98 percent of acreage and nearly all research activity of large commercial breeders. In 2007, U.S. farmers harvested 93,527,000 acres of field corn, compared with 622,946 acres of sweet corn, and 201,623 acres of popcorn (USDA, NASS, 2007 Census of Agriculture, Tables 33 and 34, available at http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp.

[6] Other early breeders include the Funk Brothers Seed Co. of Bloomington, Illinois, who had marketed hybrid corn seeds in 1916, and the Connecticut Agricultural Experiment Stations, which had sold hybrid corn seed in 1921 (Funk Bros. Seed Co., 1940; Fitzgerald 1990).

Hibberd; 227 USPQ 443 Bd. Pat. App. & Int).[7] Beginning with the first patent application in 1986 and continuing until 2005, breeders consistently reported field trial results on yields – recorded as bushels per acre – in patent applications for hybrid corn. We use these data to calculate improvements in yields – as the bottom line measure of improvements in the performance of hybrid corn. A total of 269 patents between 1985 and 2005 cover 277 corn hybrids, yielding a total of 315 patent-hybrid pairs.

Field trial data indicate that more than half of all corn hybrids that were patented between 1986 and 2005 produced *less* corn than existing hybrids. On average, patented corn hybrid yield 0.81 percent less corn than existing varieties, with a standard deviation of 4.86, highlighting the need for measures to control for the size of patented inventions.

Field trial data also show that citations are highly correlated with the size of patented improvements. Negative binomial regressions with year and firm fixed effects indicate that a 10 percent increase in yields relative to the highest-performing existing hybrid is associated with 1.9 additional citations, implying 27 percent additional citations relative to a mean of 7.1 citations (by U.S. patents issued until October 2, 2012) for the 269 patents issued between 1986 and 2005. Results are robust to alternative controls for the scope (or breadth) of patents.

Five patents are exceptionally highly cited, with up to 350 citations, respectively. On average, these patents yield 1.5 percent more corn than the highest-yielding comparison hybrid, compared with 0.8 percent less corn for the average patented corn hybrids. DeKalb's USPTO patent 6,433,261 from August 13, 2002, for DeKalb's corn hybrid *8012685* is cited 350 times and yields 2.6 percent more corn than existing hybrids. Four early patents by Pioneer and DeKalb from 1986 and 1988, however, appear to be cited mostly to establish the patentability of hybrid corn, regardless of yields. Regressions that exclude these highly cited patents indicate that a 10 percent increase in yields is associated with 1.6 additional

[7] Under regulation 35 U.S.C. 101: "Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefore…" Utility patents provide broader protection than plant patents, which have been issued for asexually propagated plants since the Plant Patent Act of 1930 (roses, other flowers and fruit trees, e.g. Moser and Rhode 2012, pp. 417-18), or Plant Variety Protection (PVP) certificates, which have been issued for sexually propagated plants (seeds) since the PVP Act of 1970.

citations, implying a 43 percent increase in citations, relative to the average of 3.63 citations in this sample.

The data also suggest that citations are a better measure for the size of patented inventions than alternatives, which have been proposed in the literature. Citations are positively correlated with patent claims, which define the subject matter of a patent, and have been used as a measure for the scope or importance of patented inventions (e.g., Sakkakibara and Branstetter 2001; Lanjouw and Schankerman 2004). Side-by-side comparisons of patent documents, however, indicate that breeders generate new patents by adding claims to existing patents, so that counts of claim increase mechanically over time. Another promising alternative measure of patent value uses the data on inventors' decisions of inventors to pay renewal fees to keep their patents active to infer patent owners' valuations of patents (Schankerman and Pakes 1986; Harhoff et al. 1999; Bessen 2008).[8] Data on renewal decisions for 269 patents of corn hybrids, however, indicate that inventors' full valuation of the patent is not observable because renewal fees are low relative to patent value. For utility patents between 1985 and 2005, renewal fees are capped at $4,110, and 98 percent of patents are renewed for the full term.[9]

I. DATA

A. Utility Patents for Hybrid Corn

Between August 26, 1986 and March 8, 2005, the USPTO issued 269 patents for hybrid field corn in subclass 800/320.1 for Maize; these patents have applications dates between February 21, 1985 and September 9, 2002.[10] Data on patent applications per year show that breeders applied for few patents for

[8] Schankerman and Pakes (1986) use renewal data for U.K., French, and German patents between 1950 and 1979 to estimate the value of patented inventions. Survey data in Harhoff et al.'s (1999) and Bessen (2008) indicate that renewal decisions are correlated with citations. Harhoff et al. (1999) find that 964 U.S. and German patents that were renewed to the full term were more heavily cited than patents their owners had allowed to expire.

[9] Data collected from the front page of patent documents at www.uspto.gov.

[10] The average patent is issued 28 months after the application, with a median of 24 months and a standard deviation of 15. The total number of patents in subclass 800/320/1 during this time is 1,181, including 488 patents for inbred corn lines, as well as patents to cover genetic modifications, such as the "terminator gene" for "Methods for maintaining sterility in plants (USPTO 5,717,129). A total of 245 patents for corn hybrids (96 percent) list *maize* as their primary subclass. The remaining 11

hybrid corn in the first years after corn became patentable. For example, DeKalb Genetics applied for two patents in 1985 (USPTO 4,607,454 and 4,629,819), immediately after the USPTO allowed the first patent for a seed, but then did not apply for another patent until 1990 (USPTO 5,589,605 for hybrid *EXP 748*, issued December 31, 1996). After 1993, patent applications began to increase, reaching 13 in 1994, 29 in 2000, and 31 in 2001.[11]

Side-by-side comparisons of patent documents indicate that breeders and their attorneys use their existing patents, which have been approved by examiners, as templates for future applications, so that patents by the same breeders typically look very similar to one another. For example, Pioneer's patent 5,574,209 for hybrid seed *3951* (filed on March 8, 1995 and issued on November 12, 1996) is nearly indistinguishable from the company's patent 5,576,472 for hybrid seed *3951* (filed on March 3, 1995 and issued on November 19, 1996).

B. Field Trial Data for Hybrid Corn

A total of 269 successful patent applications with application years between 1985 and 2005 cover 277 corn hybrids, yielding a total of 315 patent-hybrid pairs. To demonstrate to the USPTO that these hybrids were patentable, breeders voluntarily began to report field trial comparisons for all patented corn hybrids, starting with the first patent application on February 25, 1985, continuing a scientific practice of reporting field trial data in agronomy and crop science (Troyer 1990). Patent examiners do not inspect the trials, establish the protocols, or specify the reference crops, but instead require applicants to certify that the information that they provide for examination is "true and correct;" misreporting any of this information invalidates the patent (Benzion 2009).

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patents list *maize* as a secondary (cross-reference) subclass.

[11] As a result of the lag between the application and grant date, some patents for which breeders had applied late in the sample may not have been issued by March 8, 2005 and are missing from the data. Patents that cover hybrids with a higher yield increase and more citations may be issued with a shorter lag so that we may oversample such data for the later period. The correlation between size and citations, however, is stronger for the early years, possibly as a result of a switch towards strategic patenting after 1996.

In field trials breeders and farmers grow the new hybrid and existing hybrids under comparable conditions in neighboring strips of lands, with comparable soil, irrigation, exposure to sunlight and fertilizer, and record detailed data on yields and other relevant traits. Data on yields, as the bottom line "trait of major commercial interest" (USPTO patent 5,449,855, issued September 12, 1995, p.4) are reported as bushels harvested per acre planted, normalized to a moisture level of 15.5 percent, in all patent applications for corn hybrids between 1985 and 2005.[12]

In 269 patent applications, breeders report a total of 1,658 comparisons for yields for 277 newly patented corn hybrids; on average, newly patented hybrid is compared with 5.3 existing hybrids. We use these comparisons to calculate the size of the patented improvement as the difference between the corn yield of the patented hybrid and the corn yield of the highest-yielding existing hybrid for each patent-hybrid pair. For example, Pioneer files a patent for "Hybrid Maize Plant and Seed (*3375*)" on March 3, 1995 (issued on November 19, 1996, as USPTO 5,576,472, Figure 1, left patent). Pioneer's new hybrid *3375* yields 181.1 bushels per acre, and is compared with six of Pioneer's existing hybrids: *3394*, *3398*, *3379*, *3373*, *3348*, and *3417*. Among them, hybrid *3394* produces the highest yield in the field trials, 172.0 bushels per acre, implying an improvement over "prior art" by (181.1-172.0)/172.0 or 5.29 percent.

C. Counts of Citations

To examine the link between citations and the magnitude of improvements in hybrid corn, we search U.S. patents that had been issued up to October 23, 2012 for references to the 269 patents for hybrid corn. This allows us to observe citations for at least seven years after the patent is issued to capture the peak of citations over the age profile of a patent (Mehta, Rysman and Simcoe 2010).[13]

[12] Moisture levels above 15.5 percent increase drying costs and reduce farmer's income (Uhrig and Mayer 1992); data on moisture levels are consistently reported until March 8, 2005, and we have used a standard formula which farmers use to calculate income based on yields and moisture to re-estimate all tests of this paper. Comparisons that control for moisture levels yield very similar results to comparisons based on yields alone, and confirm the correlation between citations and the size of the inventive step.

[13] Mehta, Rysman, and Simcoe (2010) show that a patents "citation clock" starts with the issue date.

Among 269 patents for hybrid corn, the average patent is cited by 7.68 U.S. patents as relevant prior art between 1985 and 2012; counting each of the 315 patent-hybrid pairs as a separate observation, the average patent receives 7.10 citations. By comparison, the average patent in the NBER patent data is cited 3.0 times within 5 years, 5.3 times within 10 years, and 7.3 times within 25 years (Hall, Jaffe, and Trajtenberg 2001).[14]

D. Alternative Measures: Claims and Renewal Data

Patent claims, which specify the technology space that is covered by a patent, are a standard measure for the size, and more specifically, for the scope of patented inventions (e.g., Lanjouw and Schankerman 2004). For plants, the first claim typically covers the seed of a plant, as well as the plants that grow from that seed. Additional claims cover traits of the plant, such as heat tolerance and disease resistance, breeding methods, or sweetness and other characteristics of the plant as a food product.[15] Pioneer's USPTO patent 5,576,472, for example, includes seven claims. The first covers the seed of Pioneer's hybrid *3375*; other claims cover the plant and its parts, the pollen, the ovule, the tissues culture of regenerable cells capable of expressing all the morphological and physiological characteristics of *3375*, and a maize plant regenerated from tissue culture capable of expressing all the morphological and physiological characteristics of another Pioneer hybrid *3951*.[16] On average, 269 patents for corn hybrids between 1985 and 2005 include 24.0 claims, with a standard deviation of 13.3, a minimum of 2, a median of 28, and a maximum of 55. Counting each of the 315 patent-hybrid pairs as a separate observation, the average patent includes 25.2 claims, with a standard deviation of 13.0, a minimum of 2, a median of 29, and a maximum of 55 (Table 1).

[14] Citations until 2006 are drawn from http://elsa.berkeley.edu/~bhhall/patents.html

[15] Utility patents are assigned to primary and cross-reference subclasses based on these claims: the subclass that includes the largest number of claims is the primary subclass; subclasses that include other claims serve as cross-reference subclasses. See Lampe and Moser (2012) for an application and discussion of cross-reference subclasses.

[16] The patent explains that hybrid *3951* as intended to be grown in the Northern corn belt, while hybrid 3375 is intended to be grown in the Central corn belt, suggesting that the reference to hybrid *3951* may be a typo, which occurred when Pioneer's patent attorney recycled an existing patent application.

An alternative measure for the scope of a patent is the number of hybrids that are covered by the patent. For example, DeKalb's patent 6,072,108 covers two hybrids. On average, the 269 plant patents cover 1.23 hybrids, with a standard deviation of 1.13, a minimum of 1, a median of 1, and a maximum of 10. Similar to the recording of claims, side-by-side comparisons of patent documents also indicate that patents by DeKalb are more likely to cover additional hybrids. Pioneer's 141 patents each cover a single hybrid and its seeds; by comparison, DeKalb's 110 patents cover 1.37 hybrids with a median of 1.00, a standard deviation of 1.23, and a median of 1, and a maximum of 10 (DeKalb's patents USPTO 6,372,969 and 6,864,409). A total of 19 in 269 patents protect more than one hybrid (Table 1), all but one are assigned to DeKalb, the remaining patent is assigned to the French company Euralis.

Forty of 277 patented corn hybrids (16 percent) are covered by two or more patents; 28 hybrids are covered by 2 patents, 12 hybrids are covered by 3 patents; 35 of these patents are assigned to DeKalb, 3 to Rustica Prograin Genetique and 2 to Pioneer.[17]

Inventors' decisions to pay renewal fees create another alternative proxy for the value of patented inventions (e.g., Schankerman and Pakes 1986; Harhoff et al. 1999). We collect these data for 269 patent issues (covering 277 new corn hybrids) from the front page of patent documents at www.uspto.gov.

II. RESULTS

Among 315 patent-hybrid pairs covered in the sample, only 141 (45 percent) produced more corn than existing hybrids. On average, patented hybrids produced 0.81 percent less corn than existing hybrids, with a standard deviation of 4.86 percent. The median hybrid, US Patent No. 6,028,248 for Pioneer's 36h75, produced 0.51 percent less corn than existing hybrids. One patented hybrid, US Patent 6,646,188 for *psa104_sg*, produced 12 percent more corn than existing hybrids. Another hybrid, U.S.

[17] Patents by DeKalb are also more likely to cover a hybrid's inbred (parent) plants; 102 of DeKalb's 110 total patents cover inbred parents, in addition to the hybrid seed. By comparison, 1 of Pioneer's 137 total patents cover inbred parents.

Patent 6,362,403 for *dk591*, produced 36 percent less corn.[18] These results are consistent with statements of a patent examiner, who explained that, to be issued a utility patent, plants must only be different, but not better than existing plants (Benzion 2009).

Comparisons of yields for new and comparison hybrids (Figure 2) show that the size of patented improvements becomes smaller over time. Between 1985 and 1992, average yields of newly patented corn hybrids generally exceed the yields of existing hybrids, with 134.8 bushels per acre versus 131.7 in 1985, 135.7 versus 127.1 in 1990, 141.0 versus 138.6 in 1991, and 131.0 versus 128.6 in 1992. After 1993, newly patented corn hybrids begin to consistently yield *less* corn than existing hybrids, with 153.7 versus 158.2 in 1994, and 160.9 versus 162.9 in 2000.[19]

A. Improvements in Yields and Counts of Citations

To systematically investigate the link between improvements in yields – as a measure for the size of patented inventions – and counts of citations, we estimate negative binomial count data regressions with counts of citations as the outcome variable.[20] Counts of citations are strongly correlated with improvements in the performance of patented new hybrids. Negative binomial regressions estimate the correlation between counts of citations and the size of improvements in yield, controlling for claims, differing patent-hybrid coverage, as well as year and firm fixed effects.

$$Citations_i = \beta_0 + \beta_1 \, \%\ increase\ in\ yields_i + \delta_i + firm_i + \varepsilon_i$$

[18] Variation across examiners cannot explain this decline in the size of the inventive step. A total of nine primary patent examiners issued 269 patents for corn hybrids between August 26, 1986 and March 8, 2005. Two examiners issued 201 and 34 patents, respectively. Estimates for the size of improvements are roughly comparable across examiners.

[19] Changes in reported yields track improvements in yields for patented corn hybrids over time. At 140 bushels per acre, field trial data for patented hybrids exceed U.S. average yields by 15 to 20 percent (around 120 bushels per acre). Yields are also less variable in field trials than on the average U.S. cornfield (with a standard deviation of 144 compared with 201 for U.S. average yields), which is most likely due to controlled growing conditions in field trials.

[20] Twenty-one percent of patent-hybrid pairs receive no citations, so that OLS estimates may be biased. OLS regressions (not reported) yield substantially larger estimates for the correlation between citations and the size of the inventive step. We estimate negative binomial regressions instead of Poisson to account for over-dispersion in the dependent variable. For the baseline specification, the estimate for overdispersion is 1.19.

where the outcome variable measures *citations* to the patent in the patent-hybrid pair *i*. The explanatory variable measures the *% increase in yields* for the hybrid in the patent-hybrid pair *i*, and its coefficient β_1 measures the conditional correlation between increases in yields and counts of citations. Year fixed effects δ_t control for a mechanical increase in citations as a result of a general increase in counts of (Kortum and Lerner 1999), as well as the diffusion of computerized mechanisms to search for prior art, which may have made it easier to identify relevant citations.[21] The variable $firm_i$ controls for variation in the tendency to cite prior art across firms, e.g., as a result of variation in firms' portfolio of existing patents (Lampe 2010).

Negative binomial estimates indicate that a 10 percent increase in yields - roughly equivalent to an increase by two standard deviations - is associated with 1.93 additional citations (Table 2, column 2, significant at the 1 percent level). Compared with an average of 7.1 citations for all 269 patents in the data, this implies a 27.2 percent increase. Poisson regressions yield qualitatively similar results (Table 2, column 6).

Regressions with controls for patent scope confirm the positive correlation between increases in yields and counts of citations. Regressions with controls for counts of *claims* indicate that a 10 percent increase in yields is associated with 1.69 additional citations (Table 2, column 3, significant at the 1 percent level). Compared with an average of 7.1 citations across 269 patents for corn hybrids, this implies an increase of 23.8 percent. Controlling for patent scope through indicator variables for hybrid-patent pairs in which the *hybrid is covered by >1 patent* and for hybrid-patent pairs in which the *patent covers >1 hybrid* on citations, a 10 percent increase in yields is associated with 1.92 additional citations (Table 2, column 4, significant at the 1 percent level). Compared with an average of 7.1 citations for all 269 patents in the data, this implies a 27.0 percent increase.

[21] Alternative specifications include application year and grant year fixed effects. Grant year fixed effects control for variation in the quality of patents over time as policy changes, funding, and variation in the work load of examiners may affect the quality of patent grants. Application year fixed effects control for variation in the quality of patent applications over time, which may occur as a result of changes in industry structure and breeders' patenting strategy.

B. Claims are Correlated with Citations – but may be Added Mechanically

The analysis also suggests that counts of claims are positively correlated with citations – even controlling for the size of patented inventions. Specifically, estimates imply that a patent that includes 1 additional claim receives 0.08 additional citations (Table 2, column 3, significant at the 10 percent level). By comparison, estimates for *patent covers >1 hybrid*, as an alternative measure for patent scope, are not statistically significant controlling for the size of patents (Table 2, column 4). Estimates for the indicator variable for *hybrid is covered by >1 patent* are positive (with a marginal effect at the mean of 2.82, Table 2, column 4, significant at the 1 percent level), possibly because patents that are more valuable are more likely to be covered by 1 patent.

Side-by-side comparisons of patent documents, however, indicate that breeders may mechanically increase the number of claims on patent applications as they add new claims to existing patents to create new patents. For example, DeKalb's patent 5,912,421 is identical to DeKalb's patent 5,910,635, except for one additional claim. In 1986 and 1996, the average DeKalb patent includes 4.0 and 2.0 claims respectively; by 2004, the average number of claims had increased to 31.0. Across breeders, counts of claims increase from 4.0 in 1986, and 10.8 in 1996, to and 23.7 in 2004. DeKalb's 110 patents include on average 32.3 claims (with a standard deviation of 11.4), while Pioneer's 141 patents include on average 17.1 claims (with a standard deviation of 10.4)

B. Limiting the Sample to Patents by DeKalb

In a restricted sample of patents by DeKalb only, a 10 percent increase in yields is associated with 2.85 additional citations (Table 3, column 1, significant at the 5 percent level), implying a 31.8 percent increase, relative to an average of 8.96 citations per patent in this sample. Controlling for patent scope through counts of *claims*, a 10 percent increase in yields is associated with 2.69 additional citations (Table 3, column 2, significant at the 5 percent level), implying a 30.0 percent increase. Regressions with

alternative controls for patent scope through indicator variables for *hybrids covered by >1 patent* and for *patents covering >1 hybrid* indicate that a 10 percent increase in yields is associated with 2.91 additional citations (Table 3, column 3, significant at the 10 percent level), implying a 32.4 percent increase.

The estimated effect of *claims* continues to be positive, with marginal effect at the mean of 0.14, but, with a p-value of 0.27, is not statistically significant at conventional levels (Table 3, column 2), possibly due to the smaller size of the sample of DeKalb patents only. Estimates for alternative measures of patent scope are not statistically significant.

C. Five Highly Cited Patents (>100 Citations)

Five patents receive an exceptionally large number of citations with 350, 350, 139 137, and 136 citations, respectively. On average, these patents yield 1.49 percent more corn than the highest-yielding comparison hybrid, compared with 0.81 percent less corn for the average patented corn hybrids. DeKalb's USPTO patent 6,433,261 from August 13, 2002, for DeKalb's corn hybrid *8012685* is cited 350 times and yields 2.6 percent more corn than existing hybrids.

Four early patents by Pioneer and DeKalb from 1986 and 1988, however, appear to be cited mostly to establish the patentability of hybrid corn, regardless of yields. USPTO 4,731,499 for Pioneer's hybrid *3790* (issued on March 15, 1988) is cited 350 times and yields 2.8 percent more corn than the highest-yielding comparison hybrid (Table 6); USPTO 4,737,596 for Pioneer's hybrid *3471* (issued on April 12, 1988) is cited 139 times and yields 2.9 percent less corn than the highest-yielding comparison hybrid, while USPTO 4,629,819 (issued on December 16, 1986) for DeKalb's hybrid *dk524* is cited 137 times and yields 6.6 percent more corn than the highest-yielding comparison hybrid, and USPTO 4,607,453 (issued on August 26, 1986) for DeKalb's hybrid *dk672* is cited 136 times and yields 1.67 percent less corn than the highest-yielding comparison hybrids. Counts of citations to these patents per year indicate that citations increase dramatically with the rapid increase in patent applications after 1997.

Two of these patents, USPTO 4,607,453 and 4,629,819, assigned to DeKalb (cited 136 and 137

times, respectively), were the first patents issued after *Ex parte Hibberd*, and are cited by nearly all of DeKalb's later patents, most likely to establish the patentability of the later patents. DeKalb's patent USPTO 4,607,453 (filed on February 21, 1985, and issued on August 26, 1986) covers a

> Novel F1 hybrid corn plants DK 672, novel seeds of the hybrid, seeds produced by cultivation of the hybrid, cells which upon growth and differentiation produce the novel hybrid ad a method to produce the novel hybrid are disclosed.

DeKalb's patent 4,629,819 for a "novel hybrid corn plant" covers "F1 hybrid corn plants *DK 524*, seeds produced by cultivation of the hybrid, and plant cells which upon growth and differentiation produce the novel hybrid." It was filed on April 26, 1985 and issued on December 16, 1986 to Marvin F. Lindsey of Boone, IA, and assigned to DeKalb-Pfizer Genetics of DeKalb, IL.[22]

The most highly cited patents, with 350 citations, is Pioneer's first patent for a corn hybrid (USPTO 4,731,499 for a "Hybrid corn plant and seed," filed on January 29, 1987 and issued on March 15, 1988):

> According to the invention, there is provided a hybrid corn plant, designated 3790, produced by crossing two Pioneer Hi-Bred International, Inc. proprietary inbred lines of corn. This invention thus relates to the hybrid seed 3790, the hybrid plant produced from the seed, variants, mutants, and modifications of Pioneer hybrid 3790. This hybrid corn plant is characterized by superior yields and excellent early-season cold tolerance, and good grain quality.[23]

The "background" section for this patent includes a description of the process of breeding hybrid corn. Copies of this section are included in nearly all citing patents, including Pioneer's USPTO patent 4,737,596 for "Hybrid corn plant and seed" (filed on January 29, 1987, issued on April 12, 1988) is the third -most cited utility patent for a corn hybrid, with 139 citations. It covers Pioneer hybrid *3471*, a cross of two proprietary Pioneer inbred corn lines (*PH86471A* and *PH86471B*).

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[22] Most of the citations to this patent are from Illinois, with a small number of citations from patents issued to inventors in Iowa and Missouri. Some of the early citing patents list subclasses 271, 263, 267, 274, and 612 as their primary subclasses, but almost all citations after 2001 list subclass 320.1 for *Maize.*

[23] USPTO 4,731,499 covers a total of four claims: "What is claimed is: 1. Hybrid corn seed designated 3790. 2. A hybrid corn plant and its plant parts produced by the seed of claim 1. 3. Corn plants and the seed thereof regenerated from tissue culture of the hybrid corn plant and plant parts of claim 2. 4. A hybrid corn plant with the phenotypic characteristics of the hybrid plant of claim 2."

D. Excluding Highly Cited Patents from the Sample

Dropping the five highly cited patents increases the size of the estimated correlation between counts of citations and increases in yields. In negative binomial regressions with a restricted sample - excluding the five patents with more than 100 citations - a 10 percent increase in yields is associated with 1.55 additional citations (Table 4, column 2, significant at the 1 percent level). Compared with an average of 3.63 citations in this sample, this implies 42.7 percent additional citations. Alternative specifications, which control for variation in the scope of patents, confirm these results. Controlling for counts of *claims*, a 10 percent increase in yields is associated with 1.22 additional citations (Table 4, column 3, significant at the 1 percent level), implying a 33.6 percent increase. Controlling for patent scope *hybrids covered by >1 patent* and for *patents covered by >1 hybrid*, a 10 percent increase in yields is associated with 1.52 additional citations (Table 4, column 4, significant at the 1 percent level), implying a 41.8 percent increase.

Estimates for counts of *claims* imply that one additional claim leads to 0.11 extra citations (Table 4, column 3), confirming that claims are correlated with citations. Alternative measures for scope are not statistically significant.

E. Renewal data

Renewal data indicate that nearly all patents are renewed to the full term, leaving too little observable variation to estimate owners' valuation of patents. Among 269 patents for corn hybrids, hybrid corn in our data, 74 patents were at least 12 years old in 2011 and could have been renewed for the full term; 69 of these patents - 93 percent - were renewed to the full term. A total of 236 patents were at least 8 years old in 2011; 230 of these patents -97 percent - were renewed after 8 years; 264 patents - 98

percent - were renewed after 4 years.[24]

Such high renewal rates may be due to the small size of renewal fees, which the USPTO introduced on December 11, 1980, and which are currently capped below $5,000. In 2010, renewal fees were $980 to keep a patent active at 4 years after the issue, $2,480 at 8 years, and $4,110 at 11 years. By comparison, Pioneer's parent company DuPont devoted half of its $1.4 billion research budget to agriculture, while DeKalb's parent Monsanto devoted an unspecified share of its $1.1 billion budget to the development of new seeds (Associated Press, August 25, 2010).[25]

IV. CONCLUSIONS

Field trial data on corn yields for newly patented varieties of hybrid corn indicate that most patented hybrids do not improve on existing varieties. The size of the inventive step – measured as improvements in yields over existing hybrids – declined as breeders began to apply for more patents in the late 1990s, suggesting that the increase in patenting may have reflected a shift towards (socially wasteful) strategic patenting, rather than a true increase in innovation.

An analysis of citations data for 315 patent-hybrid pairs, however, indicates that counts of citations are robustly correlated with the size of patented improvements, measured objectively through improvements in yields. In the most conservative estimates, a 10 percent increase in yields is associated with 1.7 additional citations, implying a 24 percent increase. A small number of highly cited patents appear to be cited mostly to establish the patentability of corn hybrids. Estimates that exclude these patents indicate that a 10 percent in yields is associated with 1.2 additional citations, implying a 34

[24] Three of the five patents that were never renewed are patents that the USPTO issued to DeKalb in 1995 (after the DeKalb had been acquired by Monsanto (before DeKalb had been acquired by Monsanto on May 11, 1998): USPTO 5,436,389 issued on July 25, 1995, USPTO 5,444,177 issued on August 22,1995, USPTO 5,451,705 issued on September 19, 1995. DeKalb's foundational patent USPTO 4,629,819 (issued on December 16, 1986) received 137 citations, and was renewed at 4 and 8, but not 11 years. Only two additional patents, for dent corn hybrids, assigned to the German *Kleinwanzlebener Saatzucht AG* were not renewed for the full term: USPTO 5,929,312 issued on July 27, 1999 and USPTO 6,127,608 issued on October 3, 2000 for dent corn hybrids

[25] In annual (10-K) filings Monsanto reported its total R&D expenditure as $980million in 2008, $1,098 million in 2009 and $1,205 million in 2010 (www.monsanto.com/investors/Pages/default.aspx).

percent increase. These results suggest that counts of citations – or citations-weighted patents, which are calculated by adding citations to raw patent counts -- are in fact, a good control for the size of patented inventions, even when raw patent are compromised as a measure for improvements.

Counts of citations are also correlated with counts of claims, which define the subject matter of a patent, and have emerged as a measure for the scope (or breadth) of patented inventions. Analyses of patent documents, however, suggest that counts of claims may increase mechanically over time, as applicants add claims to their existing patents – which have already been approved by examiners – to generate additional patents.[26] Data on renewal decisions, as a measure for inventors' valuation of patents, indicate that renewal fees are too low to measure variation in inventors' valuation - except for the least valuable patents. Overall, these results suggest that citations are the most informative measure for the size of patented inventions.

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TABLE 1 – PATENT-CORN HYBRID PAIRS, 1986-2005
SUMMARY STATISTICS

	Mean	Std. Dev.	Median	Min	Max
Panel A: All patents					
Citations per patent	7.10	30.77	2	0	350
Increase in yields per acre (in %)	99.19	4.86	99.49	63.82	112.33
# of claims per patent	25.16	13.01	29	2	55
Hybrid covered by >1 patent	0.21	0.41	0	0	1
Patent covers >1 hybrid	0.21	0.41	0	0	1
Year of application (1985 + *t*)	13.07	2.64	13	0	17
Breeder					
Pioneer (N=141)	0.45	0.50	0	0	1
DeKalb (N=140)	0.44	0.50	0	0	1
Other firm (N=34)	0.11	0.31	0	0	1
Panel B: Excluding patents with > 100 citations					
Citations per patent	3.63	4.92	2	0	34
Increase in yields per acre (in %)	99.15	4.87	99.49	63.82	112.33
# of claims per patent	25.42	12.90	29.5	2	55
Hybrid covered by >1 patent	0.22	0.41	0	0	1
Patent covers >1 hybrid	0.21	0.41	0	0	1
Year of application (1985 + *t*)	13.22	2.27	13	4	17
Breeder					
Pioneer (N=139)	0.45	0.50	0	0	1
DeKalb (N=137)	0.44	0.50	0	0	1
Other firm (N=34)	0.11	0.31	0	0	1

Notes: Data consist of 315 patents – hybrid corn variety pairs for 269 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* and 278 newly patented corn hybrids. Plant breeders reported field trial data on all patent applications in this subclass during this period; we have collected field trial results and information on patent characteristics by reading all patent issues for corn hybrids (available at www.uspto.gov, accessed from October 23, 2012 to November 3, 2012). Five patents (examined in more detail below) have more than 100 citations (136, 137, 139, 350, and 350, compared with a mean of 7.10 in the full sample and 3.63 excluding them).

TABLE 2 – FULL SAMPLE, DEPENDENT VARIABLE IS CITATIONS PER PATENT

	(1) Neg. Bin.	(2) Neg. Bin.	(3) Neg. Bin.	(4) Neg. Bin.	(5) Poisson
% increase in yield	0.222***	0.193***	0.169***	0.192***	0.265***
	(0.067)	(0.055)	(0.055)	(0.052)	(0.071)
Claims			0.081*		
			(0.0434)		
Hybrid covered by >1 patent				2.820***	
				(1.058)	
Patent covers >1 hybrid				0.283	
				(0.907)	
Firm fixed effects	No	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
N	315	315	315	315	315

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Marginal effects evaluated at the mean. Data consist of 315 patents – hybrid corn variety pairs for 269 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* and 278 newly patented corn hybrids. Plant breeders reported field trial data on all patent applications in this subclass during this period; we have collected field trial results and information on patent characteristics by reading all patent issues for corn hybrids (available at www.uspto.gov, accessed from October 23 to November 3, 2012). The *% increase in yields per acre* is measured as the difference in bushels per acre between the patented hybrid and the most productive existing hybrid in the field trials. The indicator variable *hybrid covered by > 1 patent* equals 1 if the same hybrid is the subject of more than 1 utility patent. The indicator variable *patent covers > 1 hybrid* equals 1 if the same utility patent covers more than 1 patent. *Firm fixed effects* control for variation patents by DeKalb Genetics (which was acquired by Monsanto in 1996, 140 patent hybrid pairs and 110 patents), Pioneer Hi-Bred International (141 patent hybrid pairs and 140 patents) and other firms (34 patent-hybrid pairs and 19 patents).

TABLE 3 –PATENTS ASSIGNED TO DEKALB ONLY,
DEPENDENT VARIABLE IS CITATIONS PER PATENT

	(1) Neg. Bin.	(2) Neg. Bin.	(3) Neg. Bin.	(4) Poisson
% increase in yield	0.285**	0.269**	0.291*	0.358**
	(0.145)	(0.136)	(0.153)	(0.160)
Claims		0.136		
		(0.130)		
Hybrid covered by >1 patent			2.333	
			(1.430)	
Patent covers >1 hybrid			1.615	
			(1.319)	
Year fixed effects	Yes	Yes	Yes	Yes
N	140	140	140	140
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10				

Notes: Marginal effects evaluated at the mean. Data consist of 140 patent – hybrid corn variety pairs for 110 U.S. utility patents – assigned to DeKalb Genetics -- issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* and 113 corn hybrids. Plant breeders reported field trial data on all patent applications in this subclass during this period; we have collected field trial results and information on patent characteristics by reading all patent issues for corn hybrids (available at www.uspto.gov, from October 23, 2012 to November 3, 2012). The *% increase in yields per acre* is measured as the difference in bushels per acre between the patented hybrid and the most productive existing hybrid in the field trials. Three patents (examined in more detail below) have more than 100 citations (136, 137, and 350, compared with a mean of 8.96 in the full sample and 4.61 excluding them). The indicator variable *hybrid covered by > 1 patent* equals 1 if the same hybrid is the subject of more than 1 utility patent. The indicator variable *patent covers > 1 hybrid* equals 1 if the same utility patent covers more than 1 patent.

TABLE 4 –DEPENDENT VARIABLE IS CITATIONS PER PATENT
EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS

	(1) Neg. Bin.	(2) Neg. Bin.	(3) Neg. Bin.	(4) Neg. Bin.	(5) Poisson
% increase in yield	0.163***	0.155***	0.122***	0.152***	0.179***
	(0.049)	(0.044)	(0.043)	(0.042)	(0.052)
Claims			0.106***		
			(0.033)		
Hybrid covered by >1 patent				2.834***	
				(0.929)	
Patent covers >1 hybrid				0.596	
				(0.771)	
Firm fixed effects	No	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
N	310	310	310	310	310

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Marginal effects evaluated at the mean. Excluding patent 4,607,453 (136 citations); 4,629,819 (137 citations); 4,731,499 (350 citations); 4,737,596 (139 citations); and 6,433,261 (350 citations). Data consist of 310 patent – hybrid corn variety pairs for 264 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* and 272 newly patented corn hybrids. Plant breeders reported field trial data on all patent applications in this subclass during this period; we have collected field trial results and information on patent characteristics by reading all patent issues for corn hybrids (available at www.uspto.gov, accessed from October 23, 2012 to November 3, 2012). The *% increase in yields per acre* is measured as the difference in bushels per acre between the patented hybrid and the most productive existing hybrid in the field trials. The indicator variable *hybrid covered by > 1 patent* equals 1 if the same hybrid is the subject of more than 1 utility patent. The indicator variable *patent covers > 1 hybrid* equals 1 if the same utility patent covers more than 1 patent. *Firm fixed effects* control for variation patents by DeKalb Genetics (which was acquired by Monsanto in 1996, 137 patent hybrid pairs and 107 patents), Pioneer Hi-Bred International (139 patent hybrid pairs and 138 patents) and other firms (34 patent-hybrid pairs and 19 patents).

TABLE 5 –PATENTS ASSIGNED TO DEKALB ONLY
EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS

	(1) Neg. Bin.	(2) Neg. Bin.	(3) Neg. Bin.	(4) Poisson
% increase in yield	0.285**	0.269**	0.291*	0.315***
	(0.145)	(0.136)	(0.153)	(0.106)
Claims		0.136		
		(0.130)		
Hybrid covered by >1 patent			2.333	
			(1.430)	
Patent covers >1 hybrid			1.615	
			(1.319)	
Year fixed effects	Yes	Yes	Yes	Yes
N	137	137	137	137
Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10				

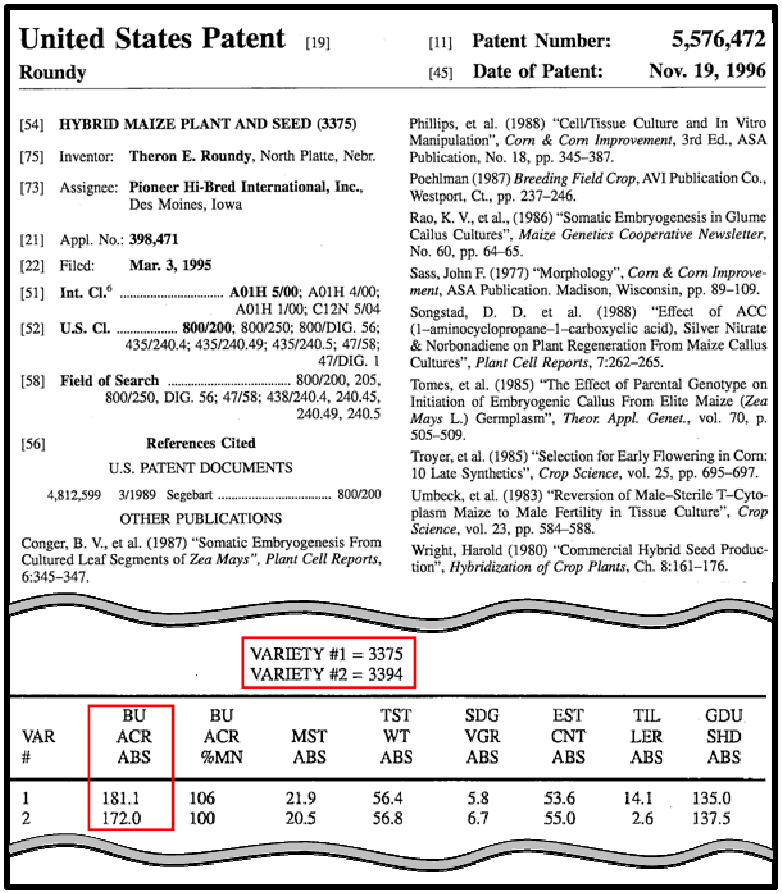
Notes: Marginal effects evaluated at the mean. Excluding patent 4,607,453 (136 citations); 4,629,819 (137 citations); and 6,433,261 (350 citations). Data consist of 107 patent – hybrid corn variety pairs for 110 U.S. utility patents – assigned to DeKalb Genetics -- issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* and xx corn hybrids. Plant breeders reported field trial data on all patent applications in this subclass during this period; we have collected field trial results and information on patent characteristics by reading all patent issues for corn hybrids (available at www.uspto.gov, accessed from October 23, 2012 to November 3, 2012). The *% increase in yields per acre* is measured as the difference in bushels per acre between the patented hybrid and the most productive existing hybrid in the field trials. The indicator variable *hybrid covered by > 1 patent* equals 1 if the same hybrid is the subject of more than 1 utility patent. The indicator variable *patent covers > 1 hybrid* equals 1 if the same utility patent covers more than 1 patent.

TABLE 6 – FIVE PATENTS WITH MORE THAN 100 CITATIONS

Patent number	Title	Application	Issue	Assignee	Hybrid	Increase in yields (%)	Claims	Total citation	Self-citations
4,607,453	Hybrid corn plants with improved standability	Feb 21, 1985	Aug 26, 1986	DeKalb	*dk672*	-1.7	5	136	125
4,629,819	Novel hybrid corn plant	Apr 26, 1985	Dec 16, 1986	DeKalb	*dk524*	6.6	3	137	124
4,731,499	Hybrid corn plant and seed	Jan 29, 1987	Mar 15, 1988	Pioneer	*3790*	2.8	4	350	7
4,737,596	Hybrid corn plant and seed	Jan 29, 1987	Apr 12, 1988	Pioneer	*3471*	-2.9	6	139	4
6,433,261	Inbred corn plant 89AHD12 and seeds thereof	Jan 8, 2001	Aug 13, 2002	DeKalb	*8012685*	2.6	28	350	348

Notes: DeKalb refers to DeKalb Pfizer Genetics; Pioneer refers to Pioneer Hi-Bred International. Self-citations are defined as pairs of originating (cited) and citing patents that are assigned to the same firm. For originating (cited) patents by DeKalb, which was acquired by Monsanto in 1996, self-citations also include citations by Monsanto. We wrote a search algorithm to match the assignees of citing and cited patents, and read through all patents that cite Pioneer's highly cited patents to identify self-citations and check the algorithm. For patent 4,737,596 the manual search yields the same four matches as the algorithm. For patent 4731499, the manual search yields seven self-citations, which we add to the count that the algorithm produced. Patents by DeKalb typically have extensive reference lists, adding a large number of citations, while Pioneer patents cite fewer patents. For example, Pioneer's patents 4731499 and 4737596 do not include any citations.

FIGURE 1 – UTILITY PATENTS FOR HYBRID CORN WITH FIELD TRIAL DATA ON IMPROVEMENTS IN YIELDS



United States Patent [19]

Roundy

[11] **Patent Number: 5,576,472**

[45] **Date of Patent: Nov. 19, 1996**

[54] **HYBRID MAIZE PLANT AND SEED (3375)**

[75] Inventor: **Theron E. Roundy**, North Platte, Nebr.

[73] Assignee: **Pioneer Hi-Bred International, Inc.**, Des Moines, Iowa

[21] Appl. No.: **398,471**

[22] Filed: **Mar. 3, 1995**

[51] **Int. Cl.**[6] **A01H 5/00**; A01H 4/00; A01H 1/00; C12N 5/04

[52] **U.S. Cl.** **800/200**; 800/250; 800/DIG. 56; 435/240.4; 435/240.49; 435/240.5; 47/58; 47/DIG. 1

[58] **Field of Search** ..... 800/200, 205, 800/250, DIG. 56; 47/58; 438/240.4, 240.45, 240.49, 240.5

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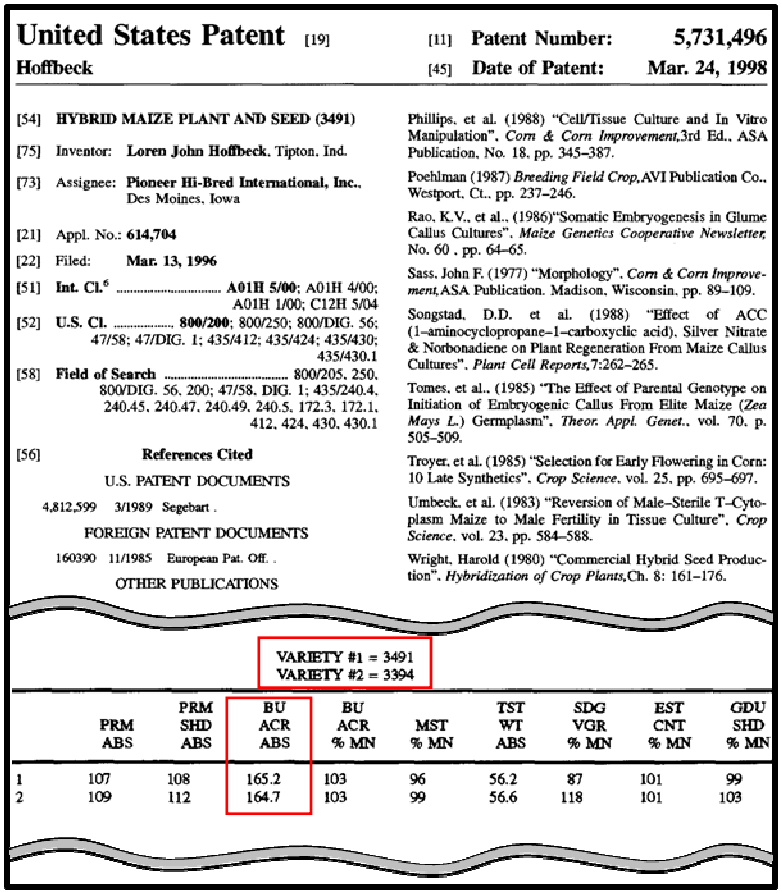
VARIETY #1 = 3375
VARIETY #2 = 3394

VAR #	BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	SDG VGR ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS
1	181.1	106	21.9	56.4	5.8	53.6	14.1	135.0
2	172.0	100	20.5	56.8	6.7	55.0	2.6	137.5



United States Patent [19]

Hoffbeck

[11] **Patent Number: 5,731,496**

[45] **Date of Patent: Mar. 24, 1998**

[54] **HYBRID MAIZE PLANT AND SEED (3491)**

[75] Inventor: **Loren John Hoffbeck**, Tipton, Ind.

[73] Assignee: **Pioneer Hi-Bred International, Inc.**, Des Moines, Iowa

[21] Appl. No.: **614,704**

[22] Filed: **Mar. 13, 1996**

[51] **Int. Cl.**[6] **A01H 5/00**; A01H 4/00; A01H 1/00; C12H 5/04

[52] **U.S. Cl.** **800/200**; 800/250; 800/DIG. 56; 47/58; 47/DIG. 1; 435/412; 435/424; 435/430; 435/430.1

[58] **Field of Search** ..... 800/205, 250, 800/DIG. 56, 200; 47/58, DIG. 1; 435/240.4, 240.45, 240.47, 240.49, 240.5, 172.3, 172.1, 412, 424, 430, 430.1

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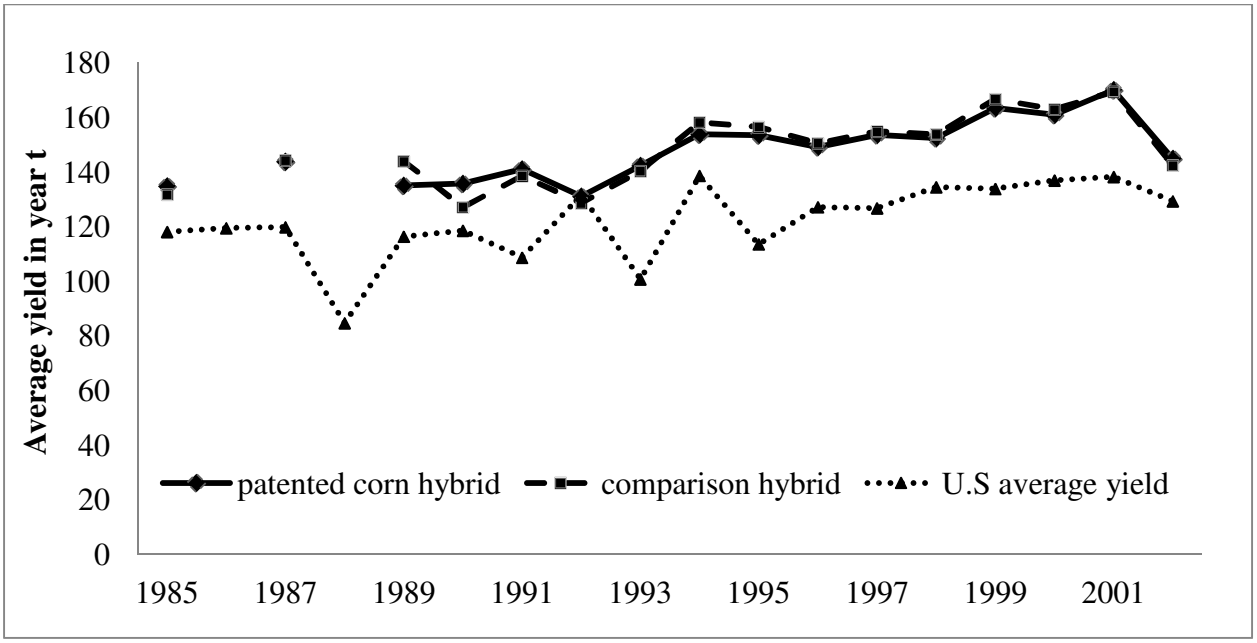
VARIETY #1 = 3491
VARIETY #2 = 3394

	PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR % MN	MST % MN	TST WT ABS	SDG VGR % MN	EST CNT % MN	GDU SHD % MN
1	107	108	165.2	103	96	56.2	87	101	99
2	109	112	164.7	103	99	56.6	118	101	103

Notes: Example of 2 out of the 256 patents granted for new hybrids in subclass 800/320.1 *Maize* between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are reported as bushels harvested per acre planted (in absolute terms, BU ACR ABS).

FIGURE 2 – AVERAGE YIELD PER YEAR
NEWLY PATENTED CORN HYBRIDS VERSUS U.S. AVERAGE YIELDS



Notes: Average yields per year of application for 269 patents and granted for new hybrids in subclass 800/320.1 *Maize* (available at www.uspto.gov). Yields are based on field trial data, which breeders report on patent applications. Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).