# PATENT CITATIONS -

# AN ANALYSIS OF QUALITY DIFFERENCES AND CITING PRACTICES IN HYBRID CORN

PETRA MOSER, NYU AND NBER,

JOERG OHMSTEDT, BAIN & COMPANY, AND

PAUL W. RHODE, UNIVERSITY OF MICHIGAN AND NBER

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Abstract:
A growing empirical literature uses patent citations as a quality-adjusted measure for innovation, despite concerns about the validity of this measure. This paper links patents with objective measures of improvements in the quality of patented inventions – measured through performance in field trials for hybrid corn – to examine three potential factors that influence citations: 1) improvements in performance 2) citing practices of patent attorneys, and 3) citing practices of patent examiners. This analysis reveals that citations are robustly correlated with performance, which confirms that citations are a useful quality-adjusted measure for innovation. The citing practices of patent attorneys and examiners, however, also influence citations. Patent attorneys cite early patents, which help establish the patentability of an invention; this practice may inflate citation counts for early patents, particularly for inventions that have only recently become patentable. Attorneys also add self-citations; our analysis indicates that that self-citations can be an indicator of follow-on invention. By comparison, examiner-added citations are typically unrelated to improvements in performance or follow-on invention.

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## 1. INTRODUCTION

Patents and citations are the standard sources of data in a growing literature on innovation, fueled in part by the availability of both measures in the NBER U.S. Patent Citation Data Files (Hall, Jaffe, and Trajtenberg 2001).[1] Empirical researchers use citations to address "the main difficulty with patent statistics": "the enormous range in the magnitude of the inventions covered" (Kuznets 1962, p. 37). Zvi Griliches (1990, p. 1669) cautions that "inventions that are patented differ greatly in 'quality,' in the magnitude of inventive output associated with them." Counts of later patents that cite a patented invention have become a popular measure for such differences in the quality of patented inventions.[2]

A key assumption in this literature is that the number of citations that a patent receives is positively correlated with the 'quality' of the patented invention. We investigate the link between citations and the quality of patented inventions by linking patents with objective measures of performance. In addition to measures for the quality of patented inventions, we investigate two major alternative determinants of variation in citations: 1) the citing practices of patent attorneys, who include citations in patent applications that they draft on behalf of their clients, and 2) the citing practices of patent examiners, who check the citations that attorneys have included and add further citations that attorneys may have missed.

Existing analysis have linked citations with a number of alternative estimates for the private or social value of patented inventions. An early study by Carpenter, Narin and Woolf (1981) documents that patents for the 100 key innovations of 1969/70 listed in *Industrial and Research Development*, were cited

[1] For example, Schmookler 1962, 1966; Sokoloff 1988; Cockburn and MacGarvie 2011; and Bloom, Schankerman, and Van Reenen 2013. More recently, a collaboration between the USPTO and Google Patents has made available the full text of U.S. patents after 1920. Empirical analyses that use these historical patent counts include Moser and Voena 2012; Kogan et al. 2012; and Moser, Voena, and Waldinger 2012.

[2] E.g., Kortum and Lerner 2000; Sørensen and Stuart 2000; Aghion et al. 2005; Regibeau and Rockett 2007; Qian 2007; Kerr 2010; Belanzon 2012. Lampe and Moser (2012) extend existing data sets of patent citations backwards to begin in the 1921 (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). In contemporary settings, All-American Seed Selection Prizes are awarded to garden varieties for sweet corn, but not to field corn, which is the subject of this analysis because it accounts for the large majority of R&D.

2.4 times more than control patents issued in the same year.[3] Trajtenberg (1990) showed that citations are correlated with the estimated *social* surplus of 456 improvements in CT scanners. Later papers have established that citations are correlated with the *private* value of patents, measured through variation in the stock market value of U.S. firms (Hall, Jaffe, and Trajtenberg 2005; Kogan et al. 2012), with valuations that R&D managers report for patents (e.g., Harhoff, Narin, Scherer, and Vopel 1999), and with the licensing revenue of non-practicing entities (Abrams, Akcigit, and Popadek 2013).

Recent analyses of citation practices, however, indicate that the citing behaviors of patent attorneys and examiners can create noise and bias in citations. For example, patent attorneys may omit relevant citations strategically to minimize their client's risk of paying license fees or triggering litigation (Sampat 2010; Lampe 2012).[4] Patent examiners, who are charged with checking these citations, also appear to miss relevant citations (Lemley 2001, p. 6; Merrill et al. 2004, p. 48), and they are more likely to cite a small set of "favorite" patents (Cockburn, Kortum, and Stern 2002, p. 6).

These issues may be particularly severe for innovations that have only recently become patentable. Lerner (2002), for example, shows that examiners of patents for financial algorithms – whose patentability was confirmed in the 1998 State Street decision - are less experienced and less likely to have a doctorate in a related field than examiners in more established fields of patentability.[5]

Our empirical application is hybrid corn, an important research area of biotechnology today, which has also been the empirical application in Griliches (1957) path-breaking empirical analysis of innovation. Hybrid corn is a particularly interesting application because some of the first biotechnology patents covered hybrid corn.[6] In 1980, the U.S Supreme Court decision in *Diamond v. Chakrabarty* (447

[3] More recently, Albert, Avery, Narin, and McAllister (2001) show that researchers at Eastman Kodak rated patents with more than 10 citations more highly than other patents in a data set of 77 patents for silver halide technologies.
[4] Alcacer and Gittelman (2006) also show that for 40 percent of 442,839 citing patents examiners added all citations, suggesting that citations on these patents are not an indicator of knowledge flows.
[5] *State Street Bank and Trust Company v. Signature Financial Group, Inc.*, 149 F.3d 1368 (Fed. Cir. 1998). Lemley and Sampat (2012, p. 820) also show that examiners add less than 10 percent of citations to non-patent prior art (such as articles in scientific journals) compared with 40 percent of citations to earlier patents. These types of biases may be particularly severe in newly patented research fields that are staffed by less experienced examiners.
[6] U.S. breeders began to create hybrids after 1908, when plant scientists discovered that seeds created from an

U.S. 303 1980), allowed the first utility patent for a living organisms: a bacterium that Ananda Chakrabarty had developed to break down different hydrocarbon components of crude oil. In 1985, the US Patent and Trademark Office (USPTO) decided in *Ex parte Hibberd* (227 USPQ 443 Bd. Pat. App. & Int) that "Tryptophan overproducer mutants of cereal crops" were patentable subject matter (US Patent 4,581,847). On August 26, 1986, the USPTO issued the first patent for a plant, for DeKalb's *Hybrid Corn Plants with improved Standability* (US4,607,453, filed February 21, 1985).[7] In their patent applications, breeders continued a long-standing practice from crop science of reporting field trial data for new hybrids.

While existing analyses have examined either citing practices or estimates of patent value, this paper investigates citing practices and performance measures in the same setting. Methodologically, we achieve this by linking patents with objective measures of performance improvements for patented inventions. For biotechnology crops, such as hybrid corn, soybean, and wheat, performance measures can be constructed from field trials, which are readily available for most crops.[8] More generally, our study illustrates the use of field trial data, as a source of objective performance measures for biological innovations.

Between 1985 and 2002, plant breeders filed 269 patent applications for hybrid corn; these patents were issued between 1986 and 2005.[9] They cover 277 corn hybrids and 315 patent-hybrid pairs with data on field trials. Baseline regressions examine whether improvements in performance – such as increased yields (output per acre) and reduced moisture content – can predict variation in citations.

This analysis reveals a strong and robust correlation between performance improvements and

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experimental cross between two inbred corn plants generated higher yields than open pollination. In 1923, the commercial introduction of Henry A. Wallace's Copper Cross initiated a shift from open-pollinated to hybrid corn. In 1933, hybrid seed was planted on less than 1 percent of U.S. corn acreage. The share had risen to almost half by 1939 and to almost the entire crop by 1960 (Griliches 1957, 1960; Olmstead and Rhode 2008).

[7] Based on regulation 35 U.S.C. 101, utility patents provide broader protection than plant patents, which have been issued for asexually propagated plants, such as roses or fruit trees since the Plant Patent Act of 1930 (Moser and Rhode 2012, pp. 417-18), or Plant Variety Protection (PVP) certificates, which have been issued for sexually propagated plants (seeds) since the Plant Variety Protection Act of 1970.

[8] For an example of field trial data for other crops see e.g. http://graincrops.ca.uky.edu/variety-testing.

[9] Pioneer Hi-Bred stops reporting moisture consistently after September 9, 2002. Later patent applications submitted by Pioneer exclude field trial data for the percent moisture (water) in corn at harvest. These data allow farmers to calculate the income that they can derive from a specific seed. See the data section for additional detail.

counts of citations. For example, marginal effects from quasi-maximum likelihood (QML) Poisson regressions indicate that a 1 percent increase in yields is associated with 0.79 additional citations for the average patent-hybrid pair, this implies a 9.48 percent increase in citations. This correlation is robust to controlling for a broad range of additional characteristics of corn hybrids including moisture (which farmers use along with yield to calculate the income from a new hybrid), relative maturity (which establishes the suitability of a hybrid to a particular climate), insect resistance, and herbicide tolerance.[10]

In the next step of the analysis, we investigate how the citing practices of patent attorneys influence the link between citations and performance. Five early patents for hybrid corn are cited by a minimum of 136 patents each. Four of these early patents are the first patents that the USPTO issued for hybrid corn. Attorneys appear to cite these patents to establish the patentability of hybrid corn. Controlling for these early patents leaves the correlation between citations and performance substantially unchanged. Regressions with an indicator variable for *first patents* indicate that a 1 percent increase in yields is associated with 0.75 additional citations. Compared with a mean of 8.3 citations, this implies a 9.03 percent increase in citations. Side-by-side comparisons of patent documents further indicate that attorneys copy and re-use sections of successful patents in later applications. This practice does not affect patent citations, but leads to a mechanical increase in the number of claims, which have been used as an alternative proxy for the quality of patented inventions.

Patent attorneys also add citations to earlier patents by the same firm, so-called *self-citations*. Hall, Jaffe, and Trajtenberg (2005, p.29) argue that self-citations "may be a reflection of the cumulative nature of innovation and the 'increasing returns' property of knowledge accumulation…" Yet, due to the empirical complexities of detecting sequential generations of inventions, it has proven difficult to trace cumulative innovation, so that empirical analyses have begun to use patent citations as a proxy.[11]

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[10] The yield performance of a hybrid is most closely related to the technological importance of an innovation, which is distinct from its private or social value. For example, Trajtenberg (1990, p. 174) explains that the value of an innovation "clearly need not be the same as technological importance: the latter could be thought of as having to do only with the supply side of innovations, whereas value obviously reflects the market equilibrium."

[11] Scotchmer (1991) formalized the concept of "cumulative" science, in which the creation of new knowledge and

Using genetic information on follow-on hybrids, we are able to investigate the link between citations and cumulative invention. QML Poisson estimates indicate that patented hybrids which breeders use to create follow-on inventions receive 2 or more additional self-citations, which implies a 46 percent increase. Notably, self-citations are not correlated with improvements in yields or income, which suggests that they may be primarily an indicator for follow-on invention.

By comparison, examiner-added citations appear to be uncorrelated with performance or follow-on invention. In interviews, patent examiners state that – to be patentable – an invention only has to be different, but not better than an existing invention. Search reports indicate that examiners apply the same standards in their search for prior art. Examiners search for physical characteristics to identify similar hybrids that should be cited as prior art, independent of performance.

## 2. DATA

Between August 26, 1986 and March 8, 2005, the USPTO issued 269 patents for hybrid corn in subclass *800/320.1 Maize*; these patents have application dates between February 21, 1985 and September 9, 2002.[12] In the early years, breeders applied for a small number of patents, possibly due to remaining uncertainty about the patentability of hybrid corn. DeKalb Genetics, for example, applied for two patents in 1985: US4,607,453 for hybrid *dk672* (filed February 21, 1985, issued August 26, 1986) and US4,629,819 for hybrid *dk524* (filed April 26, 1985, issued December 16, 1986).[13] Then the USPTO did not issue another patent to DeKalb until December 31, 1996 (more than six years after the application

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innovations depends on access to existing knowledge. Recent analyses use the term interchangeably with "follow-on" science and innovation (e.g., Furman and Stern 2011; Galasso and Schankerman 2015).

[12] 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 "Methods for maintaining sterility in plants" (US5,717,129). A total of 258 patents for corn hybrids (96 percent) list *maize* as their primary subclass; another 11 patents list *maize* as a secondary (cross-reference) subclass.

[13] US 4629819 covers "$F_1$ hybrid corn plants DK 524, seeds produced by cultivation of the hybrid, and plant cells which upon growth and differentiation produce the novel hybrid."

date on November 8, 1990).[14]

After 1993, patent applications began to increase to 13 in 1994, 58 in 1999, and 31 in 2001. This increase may have been driven by the entry of Monsanto and DuPont from the patent-intensive chemical industry into plant breeding (Moser and Wong 2015). A total of 269 successful patent applications between 1985 and 2002 cover 277 corn hybrids, all of these hybrids target the North American market (315 patent-hybrid pairs, Table 1).

### *2.1. Patent citations*

Data on patent citations are drawn from *the USPTO Patent Full-Text Database (PatFT)*, which includes citations by patents issued until October 23, 2012. This allows us to observe citations to all 315 patent-hybrid pairs for a minimum of 7 years.[15] Summary statistics indicate a rapid increase in citations after 1997, when patenting for hybrid corn increased.[16]

To check the representativeness of our data, we compare the distribution of citations to hybrid corn patents with the distribution of citations in the NBER data set. This comparison indicates that citations for hybrid corn closely match citations in the NBER data, albeit with a larger share of highly-cited patents (Appendix Figure A1).[17] In the hybrid corn data, 5 of 269 patents (1.86 percent) receive at least 136 citations or more, compared with 322 of 2.2 million patents (0.01 percent) in the NBER data.

We also collect data on citations that were added by patent examiners so that we can separately

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[14] For "*Hybrid corn with a genetic complement producing increased yield, seedling vigor, early stand, stalk strength, and low harvest moisture*." Notably, this patent was a continuation of another patent application that DeKalb had abandoned (Ser. No. 07/463,848, filed Jan. 12, 1990), which in turn had been a continuation of another abandoned patent application (Ser. No. 07/187,188, filed Apr. 28, 1988).

[15] The most recent patent in our data, US6,864,409 was filed on September 9, 2002 and issued on March 8, 2005.

[16] For hybrid corn, citations peak in 2008, nine years after the peak in patent applications and eight years after the peak in patent issues (Appendix Figure A2). By comparison, Trajtenberg (1990, p. 176) finds that citations to 456 patents for CT scanners (with application dates between December 1971 and December 1986) peaked less than 2 years (17 months) after the application date, while Mehta, Rysman, and Simcoe (2009) show that citations in a data set of 25,217,424 U.S. patents with application years between 1975 and 2001 and issue years between 1975 and 2002 peaked one year after the issue date.

[17] For patents issued between January 1, 1963 and December 31, 1999 and citing patents issued between January 1, 1975 and December 31, 1999, from http://elsa.berkeley.edu/~bhhall/patents.html, accessed in January 2013.

investigate the citing practices of attorneys and examiners.[18] Information on examiner-added citations are available for patents that were issued after December 31, 2000. Our data cover 421 examiner-added citations between January 1, 2001 and March 27, 2012 in this period, examiner added 20.1 percent of all citations. We also check whether examiners may use different standards to detect relevant prior art. Nine examiners issued 269 patents for corn hybrids between August 26, 1986 and March 8, 2005. Improvements in yields, which we discuss in the next section, are roughly comparable across these nine examiners.[19]

*2.2. Field trial data on yields*

To demonstrate the novelty of patented hybrids, seed companies reported field trial results beginning with the first application on February 25, 1985. Reporting field trial results effectively transported a practice in agronomy and crop sciences (Troyer 1990) to patent applications. In interviews patent examiners explain that they do not verify the field trials, but require applicants to certify that the information is "true and correct." Examiners generally trust reported field trial data because the potential costs of providing false information are extremely high. Misreporting results would invalidate the patent (e.g., Benzion 2009).

In field trials, seed companies and farmers grow the new hybrid and existing hybrids in neighboring strips of lands, with comparable soil, supplies of water, sunlight, and fertilizer. Data on yields serve as the bottom-line "trait of major commercial interest" (US5,449,855; issued September 12, 1995, p. 4). Other patents describe yields as a summary statistic for improvements across traits, such as adaptability to adverse soil and weather conditions, resistance to diseases, or percent of stalks standing at harvest. Yields are reported as bushels of shelled corn harvested per acre planted, normalized to a moisture level of 15.5 percent in all applications.[20]

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[18] Using *Google Patents* (available at www.google.com/patents, accessed in February 2013).
[19] The top two examiners issued 201 and 34 patents, respectively.
[20] A bushel of corn weighs 56 lbs. or 25.4 kg. An acre contains 4,046.86 square meters.

In 269 patent applications, seed companies report a total of 1,658 yield comparisons for 277 hybrids; the average newly patented hybrid is compared with 6.0 existing hybrids. We use these comparisons to measure improvements in performance as the yield difference between the patented hybrid and the best comparison hybrid. For example, DeKalb's hybrid *dk524* (US4,629,819) yields 136.5 bushels per acre and is compared with DeKalb's *T1000*, and Pioneer's hybrid *3732*. Hybrid *3732* has the higher yield, with 128.0 bushels per acre; we use this comparison to calculate the implied performance improvement as (136.5-128.0)/128.0, which equals 6.6 percent.

Improvements in yields can be measured for all 315 patent-hybrid pairs between 1985 and 2002, and follow a bell-shaped distribution, with a peak at a 1.0 percent (Figure 1). Among 315 patent-hybrid pairs, 143 pairs (or 45 percent) produced more corn than the highest-yielding existing hybrid in the same field trial. On average, patented hybrids produced 0.6 percent less corn than the highest-yielding comparison hybrids, with a standard deviation of 4.2 percent (Table 1, Panel A).

Improvements in yields were higher in the initial period but declined with the sharp rise in patent applications in the 1990s. For most years between 1985 and 1992, the average yield of newly patented hybrids exceeded the average yield of comparison 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 (Appendix Figure A3). After 1993, patented hybrids consistently yield *less* corn than comparison hybrids, with 153.7 versus 158.2 in 1994, and 160.9 versus 162.9 in 2000.

As a check on the quality of the data, we compare reported yields from patents with reported yields in the records of the United States Department of Agriculture (USDA). This comparison shows that reported yields in patents closely track reported yields in the USDA data (Figure A3). At 140 bushels per acre, field trial yields for patented hybrids exceed US average yields by 15 to 20 percent (around 120 bushels per acre). Due to the controlled growing conditions in field trials, reported yields in patent documents are also less variable than the USDA averages (with a standard deviation of 144 compared with 201 for U.S. average yields), which is in line with the controlled growing conditions in field trials.

*2.3. Other traits*

Small and declining improvements in yields suggest that focusing exclusively on yields may miss other traits that breeders target with their R&D. For example, a section in US6,433,261 explains that

> "to commercialize a hybrid, it is not necessary that the hybrid be better than all other hybrids. Rather, significant improvements must be shown in at least some traits that would create improvements in some niches. …Typically, about 10 to 15 phenotypic traits, selected for their potential commercial value, are measured."

Breeders report these traits less consistently than yields, but the available data are suggestive and deliver a more complete picture of variation in performance.

Most importantly, farmers consider variation in *moisture* when they calculate gross incomes for different hybrids. A typical calculation takes the market price of corn as given and assumes a drying cost of $0.02 for each percentage point moisture 15.5 (e.g., US6,835,877 for Pioneer's hybrid *34m94*). A "Grain Quality Fact Sheet" of Purdue's Agricultural Extension Service of Purdue University (Uhrig and Maier 1992) explains:

> "Corn is physiologically mature when the ears reach 35% moisture. Corn can be field-shelled with a combine at moisture contents of 35+% moisture. Shelled corn must be dried to around 15% moisture and cooled with aeration to prevent spoilage (heating). Corn with moisture contents above 15% is discounted in the marketplace. … The extra expense will be in the form of increased fuel costs and drying time (less drying capacity)."

*Moisture* is reported as the percentage of water weight at harvest; this information is available for all 315 patent-hybrid pair. Pioneer Hi-Bred stopped reporting moisture consistently after September 9, 2002. We stop the data collection for patent applications on that date; all of these patents are issued by 2005. On average, patented hybrids show an improvement of 0.3 percent less moisture than the highest-yielding comparison hybrids, with a standard deviation of 5.3 percent (Table 1, Panel A).

Another important trait is *relative maturity*; it determines to suitability of hybrids across climatic conditions. Coulter and Van Roekel (2009) explain that farmers use an ordinal measure of *relative maturity* as the first cut to identify hybrids that can flourish in their growing region, and then select 'top performers' in terms of yields and income per acre within their growing region. Major seed companies encode *relative maturity* in the product name of new hybrids. For example, the second digit of Pioneer's hybrid name categorizes relative maturity on a scale from 0 (needing a long time to grow) to 9 (needing a very short time only).[21] The digit 9 in the product code 39r34 (US6,797,868 granted on September 28, 2004) indicates that this hybrid has a very short relative maturity. These data are available for 138 of 141 Pioneer hybrids. For DeKalb/Monsanto, the first two digits of a hybrid's name categorize relative maturity. These data are available for 21 of 120 DeKalb/Monsanto hybrids, and relative maturity ranges from 44 (needing a short time to grow) to 74 (requiring a long growing season).[22]

Comparisons of relative maturity indicate that patented hybrids and comparison hybrids target similar growing regions (Appendix Figure A4).[23] Among 84 of 138 Pioneer hybrids (60.9 percent) have the same relative maturity as the comparison hybrid; another 50 hybrids (36.2 percent) are a single category away from the comparison. Only 4 (2.9 percent) are two categories away and none are more distant. Among 21 hybrids by DeKalb and Monsanto, 6 hybrids (28.6 percent) have the same relative maturity as the comparison; 7 hybrids (33.3 percent) are a single category away, 3 (14.3 percent) are 2 categories away and another 4 (19.0 percent) are 3 categories away.

In addition to variation in yields, moisture, and relative maturity, farmers also consider *insect resistance* and *herbicide tolerance* in their purchasing decisions (Coulter and Van Roekel 2009).[24] U.S. breeders developed the first *insect resistant* corn hybrid 1996 by inserting a gene from the soil bacterium *bacillus thuringiensis* (Bt) into corn. The resulting Bt corn produces a protein that is toxic to the European corn borer and other insects (Fernandez-Cornejo and Wechsler 2012). *Herbicide tolerance*, was introduced in the same year. Monsanto's *Round-up Ready* corn, for example, withstands the application of glyphosate (*Round-up*) and other powerful herbicides. This trait allows farmers to reduce labor costs by applying herbicides instead of weeding (Fernandez-Cornejo et al. 2014). By 2013, 76 percent of U.S. corn acreage was Bt corn, and 85 percent was herbicide tolerant (USDA-ERS 2013).

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[21] See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming practices.
[22] For the remaining 99 hybrids, breeders report development (rather than product) codes, which do not allow us to match patents with data on relative maturity.
[23] Chi-square tests fail to reject the hypothesis that these distributions are identical for patented and comparison hybrids with a p value of 0.684 for Pioneer, and a p-value of 0.674 for DeKalb and Monsanto.

We measure variation in *herbicide tolerance* and *insect resistance* by linking product codes in the patent document with product codes in catalogues, press releases, and independent field trials. Product codes are available for 165 hybrids.[25] Eleven are *insect resistant*, three are *herbicide tolerant*, and one hybrid has both traits.[26]

*2.4. Follow-on inventions*

Patented hybrids can also be commercially valuable because they serve as inputs (parents) to follow-on hybrids. To identify hybrids whose value may be determined by their importance as an input to follow-on or cumulative invention (Scotchmer 1991, Galasso and Schankerman 2015), we match patented hybrids with genetically similar hybrids introduced by the same breeder within a five-year window of the original patent application. We capture follow-on hybrids using seed catalogues, press releases, and field trial reports. Catalogue entries include information on the "base genetics" of the hybrid; this information "identifies the non-converted hybrid which has been modified to include new trait(s)," such as insect resistance or herbicide tolerance (Pioneer 2006, p.7). Pioneer's (2006, p. 1) product catalogue for example, lists hybrid *39k40* (US6,809,242, not insect resistant) as a parent for the insect resistant hybrid *39k41*.

For 165 hybrids, *follow-on* hybrids is available for a minimum of 5 years.[27] For 58 hybrids of these hybrids (35 percent) we observe a genetically related follow-on hybrid. Among 58 follow-on hybrids, 34 hybrids have both traits; another 21 are insect resistant, and another 3 are herbicide tolerant.[28]

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[25] For the remaining 112 hybrids, breeders report *development* codes, which are not reported on field trials or other sources of data on herbicide tolerance and insect resistance. See the Table A12 for a list of field trials.

[26] Appendix Table (A1) presents additional traits, including *stalk lodging*, *dry-down* and *vigor*, which we examine in an additional set of robustness checks (Appendix Table A2).

[27] Data for Pioneer are drawn from Pioneer's "Corn Hybrid-Herbicide Management Guide" (2004, 2005 and 2006 edition). For other hybrids (by Monsanto/DeKalb and KWS Kleinwanzlebener Saatzucht), we collect data on follow-on hybrids from press releases and field trial reports (Appendix Table A10).

[28] DeKalb/Monsanto begin to use development codes in 1996, and Pioneer follows in 1998. This switch breaks the link between patents and product names which made it possible to identify follow-on hybrids, and observe their performance in field trials.

## 3. RESULTS

In this section, we investigate three alternative factors that may determine variation in the counts of patent citations: improvements in performance and follow-on inventions, citing practices of patent attorneys, and citing practices of patent examiners.

### *3.1. Performance and follow-on invention*

Plots of citation counts and yields suggest that citations are strongly correlated with improvements with yields (Appendix A5). To further investigate this correlation we estimate quasi-maximum likelihood (QML) Poisson regressions. We focus on QML Poisson (using OLS as a robustness check, Appendix Table A6) because the outcome variable *citations* is a count variable and 22.2 percent of hybrid patent pairs receive zero citations.[29]

$$E(citations_i) = exp\{ ß_1\, yields_i + ß_2\, moisture_i + \delta_t \}$$

where *citations* counts citations to patent *i*, and the explanatory variable *yields* measures the percent increase in yields for the patent-hybrid pair *i* (computed as the difference between the yield of the patented hybrid and the highest-yielding existing comparison hybrid, divided by the yield of the highest-yielding comparison hybrid). The variable (relative) *moisture* measures the water content of a hybrid at harvest relative to the water content of the highest-yielding comparison hybrid. Fixed effects $\delta_t$ for the application years of cited patents control for a potential increase in citations over time, independent of the quality of patents. For example, patent citations may increase because patenting increases overall (e.g., Kortum and Lerner 1999), or because computerized search makes it easier to identify relevant citations.[30]

Baseline estimates confirm that patent citations are highly correlated with improvements in

[29] QML Poisson estimates are consistent and preferable to OLS when a disproportionate share of the values of the outcome variable are zeros (Wooldridge 1999). In the unconditional QML Poisson model, fixed effects enter as dummy variables; this approach makes it possible to estimate average marginal effects (as the average of marginal effects evaluated across all observations in the sample) and marginal effects (evaluated at the sample mean).
[30] Application year fixed effects also control for potential truncation problems, which however, should be small because we are observing citations for each patent for a minimum of seven years. Robustness checks with grant year fixed effects confirm the results of the main specification (Appendix Table A5). Grant year fixed effects control for variation in the quality of patents as a result of variation in funding and the work load of examiners.

yields. A 1 percent increase in yields is associated with 0.79 additional citations (Table 2, column 2, significant at 1 percent). Relative to a mean of 8.31 citations across all 315 patent-hybrid pairs, this implies a 9.48 percent increase. Confirming the role of yields as a summary statistic for improvements in new hybrids (e.g., Griliches 1957, 1960; Olmstead and Rhode 2008), estimates for *moisture* are small and not significant (with an estimate of -0.1 and a p-value of 0.609, Table 2, column 2). The correlation between yields and citations is also robust to excluding *moisture*; a 1 percent increase in yields is associated with 0.76 additional citations (Table 2, column 1, significant at 1 percent), which implies a 9.19 percent increase in citations.[31]

Additional robustness checks examine the effect of *stalk lodging*, *dry-down* and *vigor* on citations (Appendix Table A2). We do not include these variables in the main specifications because they are not consistently reported, and because the agronomic literature suggests that their effects are largely captured through variation in yields and moisture. For example, Coulter and Van Roekel (2009) explain "Since corn has a narrow optimum plant population, unharvestable ears due to stalk and root lodging will have a large impact on yield. In a hybrid trial conducted in northwest Iowa in 2005, where severe lodging was present, each 1% increase in lodging reduced yield by an average of 0.5 bushels per acre."

In regressions, the estimated effects of the additional traits are close to zero and not statistically significant. The positive correlation between yields and citations is also robust to controlling for additional traits. Estimates with controls for stalk lodging imply that a 1 percent increase in yields is associated with 0.59 additional citations (Table A2, column 1). Compared with a mean of 10.13 citations per patent-hybrid pair, this implies that a 1 percent increase in yields is associated with a 5.84 percent increase in citations. Estimates remain significant in all regressions as long as the sample size remains

[31] As an additional robustness check, we control for the significance of the variables *yields* and *moisture* themselves (instead of the significance of their regression coefficients) by setting the variable *yields* to zero in case the difference in yields between the patented hybrid and the comparison hybrid is not significant at the 1% level. Similarly, the variable moisture is set to zero in case the difference in moisture between the patented hybrid and the comparison hybrid is not significant at the 1% level. Poisson specifications with these adjusted *yields* and *moisture* variables confirm the results of the main specifications (Appendix Table A3). Similarly, we carry out a robustness check to control for cases of multiple patents per hybrid and cases of multiple hybrids per patent (as descripted above). Again, Poisson specifications confirm the results of the main specifications (Appendix Table A4).

above 42 observations (Table A2, column 2 and 3).

We also control for two other major improvements in corn hybrids – insect resistance and herbicide tolerance – which may influence the value of a new hybrid above and beyond their effects on yields. We include indicator variables for hybrids that carry these traits (*insect resistant* and *herbicide tolerant*), as well as for hybrids that serve as an input for follow-on GM hybrids that carry the trait (*insect resistant follow-on hybrids* and *herbicide tolerant follow-on hybrids*).

Including these additional controls increases the estimate for *yields* to 0.87 additional citations (Table 2, column 4, significant at 10 percent); relative to a mean of 8.31 citations this implies a 10.43 percent increase in citations for each 1 percent increase in yields. Estimates for the indicator variables *insect resistant* and *herbicide tolerant* are not significant (Table 2, column 4, with p-values of 0.206 and 0.241, respectively). Estimates also indicate that patent hybrid pairs with *insect resistant follow-on hybrids* receive 4.30 additional citations (Table 2, column 4, significant at 5 percent), which implies a 51.73 percent increase. Similarly, patent hybrid pairs with *herbicide tolerant follow-on hybrids* receive 6.99 additional citations (Table 2, column 4, significant at 1 percent), which implies an 84.11 percent increase.

### *3.2. Citing practices of patent attorneys*

Next we examine the influence of patent attorneys, who draft patent applications on behalf of their clients. Side-by-side comparisons of patent documents reveal striking similarities across patent documents that were drafted by the same attorneys, which suggests that attorneys use successful patents as a template for later applications. For example, Pioneer's patent US5,574,209 for hybrid *3951* (filed March 8, 1995, issued November 12, 1996) is nearly indistinguishable from Pioneer's patent US5,929,311for hybrid *32j55* (filed January 31, 1997, issued July 27, 1999).

Five patents in the data receive between 136 and 390 citations each, compared with a maximum of 34 citations for all remaining patents (Figure A5). On average, these patents yield 1.5 percent more corn than the best highest-yielding comparison hybrid. A closer look at the text of the patent documents, however, suggests that attorneys cite these patents to establish the patentability of new corn hybrids. Two of DeKalb/Monsanto's most cited patents - US4,629,819 (filed April 26, 1985, issued December 16, 1986) and US4,607,453 (filed February 21, 1985, issued August 26, 1986) were the first patents after the USPTO decided that plants could be patented (*Ex parte Hibberd* 227 USPQ 443 Bd. Pat. App. & Int). DeKalb's attorneys cite these patents on nearly all of their patent applications; US4,629,819 is cited 137 times, and US4,607,453 is cited 136 times. A third patent - Pioneer's US4,737,596 (filed January 29, 1987, issued April 12, 1988) - is commonly cited as a third patent with the two early DeKalb patents. For example, 22 patents cite the three patents as a group in 1997, and 17 patents cite them as a group in 2002 (Appendix Figure A2).[32]

Pioneer's patent US4,731,499 for "Hybrid corn plant and seed" (filed January 29, 1987, issued March 15, 1988) – was the third patent to be issued after DeKalb's first two patents, and it receives 693 citations (Table 3).[33] Its background section includes a description of the process of breeding hybrid corn; this description is copied verbatim by nearly all citing patents. Another highly cited patents is Pioneer's patent US4,737,596 (filed January 29, 1987, issued April 12, 1988); it has 139 citations.[34] Pioneer's patent attorneys typically cite US4,731,499 together with US4,737,596; until 2001, nearly all citations to the two patents are joint (Appendix Figure A2).

Controlling for early patents leaves the estimates for yields substantially unchanged. A 1 percent increase in yields for a patented hybrid is associated with 0.75 additional citations (Table 4, column 1, significant at 1 percent). Compared with a mean of 8.31 citations, this implies a 9.03 percent increase in citations. The estimate for *first patents* implies that – controlling for yields and moisture - the five early patents received 36.34 additional citations (Table 4, column 1, significant at 1 percent).

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[32] The most recent among the highly cited patents is DeKalb's patent US6,433,261 (issued August 13, 2002) and is cited 390 times. Patent attorneys may cite it because they included it to their pool of cited patents used on multiple patent applications to incorporate previous examiner-added citations (see section 3.3 below for a detailed description). It is cited by later patents along with US4,731,499.

[33] It covers hybrid *3790*, which yields 2.8 percent more corn than the comparison hybrid (Table 3).

[34] This patent covers hybrid *3471*, which according to the patent grant "is characterized by superior qualities of good ear size, excellent late-season plant health and seedling (young plant) vigor, and fast dry-down in the field."

As an additional robustness check, we exclude examiner-added citations (which can be observed for citations after 2000) from the dependent variable. This tests leaves the estimates substantially unchanged. Excluding examiner-added citations, a 1 percent increase in yields is associated with 0.74 additional citations (Table 4, column 2, significant at 1 percent). Compared with a mean of 5.74 citations, this implies a 12.94 percent increase. Estimates for the indicator variable for early patents also stay very similar, and imply that – controlling for yields and moisture - the five early patents received 29.92 additional citations (Table 4, column 2, significant at 1 percent).

Re-estimating the baseline regressions with *self*-citations as the dependent variable confirms that self-citations "may be a reflection of the cumulative nature of innovation" (Hall, Jaffe, and Trajtenberg 2005, p. 29).[35] Patents for hybrids with at least one *insect resistant follow-on hybrid* receive 2.06 additional self-citations (Table 4, column 6, significant at 5 percent). Compared with a mean of 4.44 citations, this implies a 46 percent increase. Patents for hybrids with at least one *herbicide tolerant follow-on hybrid* receive 3.69 additional self-citations (Table 4, column 6, significant at 1 percent), which implies an 83 percent increase. The coefficient for *yields* is not significant for self-citations (Table 4, column 6, p-value 0.510). This result suggests a role for self-citations as an indicator for follow-on inventions.

As a complementary test, we investigate the impact of attorney practices on two alternatives measures for the quality of patented inventions: counts of patent claims and inventors' decisions to pay renewal fees. Patent claims specify the technology space covered by a patent, and empirical studies have used the number of patent claims as a measure for breadth or scope of patents. For plants, the first claim typically covers the seed and the plant that grow from that seed. Additional claims cover traits such as heat tolerance or disease resistance.[36] For example, Pioneer's patent US5,574,209 includes seven claims.

[35] Following Jaffe (1998), we define self-citations as citations from patents by the same firm. Self-citations include examiner-added citations (roughly 20 percent of citations after December 31, 2000), which we below.
[36] Patent examiners use claims to assign patents are to primary and cross-reference (secondary) subclasses. 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-

The first covers the seed of Pioneer's hybrid *3951*; 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 *3951*, and a maize plant regenerated from tissue culture capable of expressing all the morphological and physiological characteristics of *3951*. Note that US5,576,472 - the very next Pioneer patent – includes the same seven claims for its hybrid *3375* using the same language.[37]

This example illustrates how attorneys reuse the text of successful patent applications, by copying and pasting text directly from successful applications. This practice lead to a mechanical increase in the number of patent claims over the tenure of an attorney with a breeder.[38] Pioneer's claims, for example, increase in a step-wise process from 5.0 claims per patent in 1989, the first year when Pioneer uses its in-house attorney, to 28.4 claims per patent in 2000, the last year when Pioneer uses its in-house attorney (Figure 2). When Pioneer switched to the outside legal firm McKee, Voorhees and Sease, counts of claims declined to 21.3 claims per patent in 2000, and then increased again to 24.4 in 2001.[39] On average, 269 patents for corn hybrids between 1985 and 2002 include 24.0 claims (Table 6).[40] For 12 of 13 breeder-attorney pairs claims per patent increase over time.[41]

In addition to drafting patents, attorneys also make decisions about paying renewal fees; these decisions create a measure for the private *value* of patents. 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. (1999) and Bessen (2008) indicate that renewal decisions are

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reference subclasses, and Lanjouw and Schankerman (2004) for a more detailed discussion of claims.

[37] Attorneys also vary systematically in the way they structure patents. All of Pioneer's 142 patents cover a single hybrid, whereas 17 patents by DeKalb and 1 patent by Euralis cover more than one hybrid. On average, DeKalb's 110 patents cover 1.4 hybrids (with a standard deviation of 1.2). Forty of 277 patented corn hybrids (14 percent) are covered by two or more patents; 35 of these patents are assigned to DeKalb, 3 to Rustica Prograin Genetique and 2 to Pioneer. 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 patented hybrid. By comparison, 1 of Pioneer's 142 patents for hybrids also covers inbred parents. We control for such variations in robustness checks (Appendix Table A4).

[38] Included in claim 7 of US5,576,472 (for hybrid *3375*) is even a text passage, which erroneously references hybrid *3951* (which is subject of US5,574,209), instead of hybrid *3375*. This is most likely a typo due to cut-and-paste.

[39] Claims by DeKalb/Monsanto follow a similar pattern, but are more difficult to separate into attorney breeder pairs because DeKalb/Monsanto switches more frequently between patent attorneys.

[40] Across 13 breeder-attorney pairs in our data, the average number of claims ranges from 3.0 to 50.0 (Table 6).

[41] Rustica Prograin Genetique and the legal firm Patterson, Thuente, Skaar & Christensen (who account for only 3 of 269 patents) is the only breeder-attorney pair for whom counts of claims do not increase over time.

correlated with citations.[42] In our sample, nearly all patents are renewed to the full term, leaving little observable variation to estimate owners' valuation of patents. Among 269 patents for corn hybrids, hybrid corn in our data, 233 patents were at least 12 years old in 2014 and could have been renewed for the full term; 227 of these patents (97.4 percent) were renewed to the full term (Table A9). A total of 36 patents were at least 8 years old in 2014; all were renewed after 8 years.

Renewal rates around 100 percent are a likely consequence of low renewal fees. In 2010, for example, renewal fees were $980 to keep a patent active at 4 years after the issue, $2,480 at 8 years, and $4,110 at 12 years.[43] Renewal fees in this range are negligible compared with the size of research budgets for companies like Monsanto and Pioneer, around $1.1 billion.[44]

*3.3. Citing practices of patent examiners*

Previous papers have examined the influence of examiners on citations (Alcácer and Gittelmann 2006; Criscuolo and Verspagen 2008; Alcácer, Gittelman and Sampat 2009; Hegde and Sampat 2009); we build on this work by simultaneously investigating the influence of the characteristics of inventions. Systematic data on examiner-added citations are available for patents issued after 2000. The share of examiner-added citations for corn hybrids is roughly comparable to chemistry, higher than drugs, and lower than mechanical inventions: 18.9 percent of citations to hybrid corn patents issued between January 2001 and August 2003 were added by examiners, compared with 11.1 percent of citations for patents issued in drug and medical fields, 22.2 percent in chemicals, and 40.0 percent for mechanical inventions (Alcácer and Gittelman 2006).[45]

We also examine the full text of patent documents to investigate the type of citations that

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[42] Harhoff et al. (1999), for example, find that 772 German patents, which inventors renewed to the full term of 18-years (at a cost of 16,075DM) were more highly cited than other patents, which inventors allowed to lapse.
[43] Available at http://www.uspto.gov/patents/process/maintain.jsp, accessed June 2014.
[44] Associated Press, August 25, 2010. In 10-K filings Monsanto reported total R&D expenditures of $980 million in 2008, $1,098 million in 2009 and $1,205 million in 2010 (www.monsanto.com/investors/Pages/default.aspx).
[45] For citing patents issued until August 2003. Extending the data to include application dates until 22 June 2011 (the application date of the last patent in the data), increases the share of examiner-added citations to 20.12 percent.

examiners add to patent applications. This analysis suggests that examiners are most likely to add citations to more recent, newly issued patents. In the *References Cited* section of a patent document, cited patents are listed by their age, starting with the oldest patents. Nearly one-third of all examiner-added citations (135 in 421) are the last and most recent cited. By comparison, 20 examiner-added citations refer to the oldest patent in the list, which is most frequently a foundational patent (e.g., to establish patentability); patentees then appear to copy citations to these patents.

The data confirm that examiners are more likely to cite a small group of favorite patents, possibly because they usefully "describe ('teach') the technology area and the bounds of prior art" (Cockburn, Kortum and Stern 2002, pp. 6-7). Examiners for 269 corn patents added a total of 385 citations; among 385 cited patents, the median patent is cited once by an examiner, and the average patent is cited 1.1 times with a standard deviation of 0.3. Only a single patent - US5,859,355 for the "Inbred corn plant 17DHD12 and seeds thereof" - is added 29 times by the same examiner, which indicates that it was among the examiner's "favorite" patents. Interestingly, the same patent is added only once by another examiner, and only 4 times by a patentee.

Once patent examiners have cited a patent, patent attorneys tend to incorporate the new citations to their own pool of cited patents. Among 198 cited patents in applications after 2000, 128 (64.7 percent) were first cited by an examiner. By comparison, 70 patents were first cited by a patent attorney. For example, an examiner added DeKalb's patent US6,433,261 for "Inbred corn plant 89AHD12 and seeds thereof" (by Jay R. Hotchkiss filed January 8, 2001, issued August 13, 2002) to three patents issued in 2006 and 2007 (US6,989,478; US7,173,171; and US7,186,906). After the examiner had added these patents to the first few patents, patent attorneys follow her lead and cite the patents in another 384 applications.[46]

[46] Among 390 total citations to these patents, only 6 are added by the examiner after the initial citations. Using both hand-collected and algorithm-collected data, we also find that examiner-added citations are more frequent in early cohorts after 2000. Machine-collected data include 22 hybrid corn patents issued between January 2001 and August 2003 (to match the range of data in Alcácer and Gittelman (2006); collected from www.google.com/patents, accessed in February 2013). These 22 patents receive 71 citations, including 28 examiner-added citations, which

To investigate the effects of examiner practices on citations more fully, we estimate the baseline specification with examiner-added citations as the dependent variable. These regressions suggest no meaningful link between examiner-added citations and performance (or significance to follow-on invention). Estimates for *yields* are small and not statistically significant (0.02 with a p-value of 0.548, Table 5, column 6). In contrast to self-citations, examiner-added citations are also a poor predictor for follow-on inventions. Coefficients for *insect resistant follow-on hybrid* and *herbicide tolerant follow-on hybrid* are -0.02 and -0.08, respectively, and not statistically significant (with p-values of 0.926 and 0.728, respectively, Table 5, column 6).[47]

Interviews and informal communications with patent examiners confirm that patent examiners put little weight on improvements in performance or an invention's significance to follow-on research. For example, Gary Benzion (October 26, 2009), explain that patentability only requires a new hybrid to be *different but not better* than existing hybrids that have been patented already.[48]

We follow up on these statements by analyzing examiners' search reports for patents that cite the 269 hybrid corn patents in our data. Search reports document the key word searches that examiners use to search for prior art. To the best of our knowledge, these reports have not been used in previous analysis, possibly due to the difficulty of linking examiner-added citations with a specific search report. We are, however, able to establish this link because one patent examiner (David T. Fox) includes patent numbers to his key word searches between 2002 and 2011. These reports confirm that examiners use physical traits – independent of performance - to identify patents that should be cited as prior art. For example, examiner

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implies a 39.44 percent share of examiner-added citations. By comparison, hand-collected data include 23 hybrid corn patents issued between January 2001 and August 2003. These 23 patents include US5,444,177 for maize, which is missing from the machine-collected data. In cohorts of citing patents until October 2012, these patents receive 183 citations, including 34 examiner-added citations until October 2012, which implies a 12.6 percent share.

[47] Since examiner-added citations are only available for patents that were issued after 2000, we also re-estimate the baseline specification for all (examiner-added and other) citations for patents that were issued after 2000. These data indicate that a 1 percent increase in *yields* is associated with 0.91 additional citations (Table 5, column 2, significant at 5 percent). Patent-hybrid pairs which serve as an input to at least one *insect resistant follow-on hybrid* receive 3.48 additional citations (Table 5, column 3, significant at 5 percent), while estimates for *herbicide tolerant follow-on hybrid* indicate 5.89 additional citations (Table 5, column 3, significant at 1 percent).

[48] In addition to Examiner Benzion, we also communicated with Examiner Anne Marie Grünberg in October 2009 and with four other officials at U.S. and international patent offices between October 2009 and October 2013.

Fox adds a citation to US6,759,577 (for Pioneer's hybrid *37y15*) to Pioneer's patent US7,087,821 (for hybrid *33y45*). To check for prior art, Examiner Fox performed 18 distinct searches (Table 7); all of these searches include search terms for physical characteristics such as "(anthocyanin = 'faint' or 'light') and (leaf = 'dark green') and (glume = 'purple') and (ear = 'horizontal') and (cob = 'red')." In sum, the available quantitative and qualitative evidence indicates that examiner-added citations would be a poor predictor for performance improvements and other measures for the commercial values of patented inventions.

## 4. Conclusions

Patent citations have quickly become the standard measure for quality-adjusted innovation, despite concerns about the processes that generate citations (e.g., Lampe 2012; Cockburn, Kortum, and Stern 2002). This paper has linked patents with objective measures on performance improvements to examine the processes that generate citations and investigate whether citations are a good proxy for quality-adjusted innovation.

The focus of our analysis is hybrid corn, which was already the subject of Griliches (1957) seminal analyses innovation, and continues to be an economically important, research-intensive industry today. Moreover, hybrid corn is an example of an industry in which innovations have only recently become patentable, so that insights from hybrid corn can also help to shed light on the processes that influence citations for research fields in which patentability is new.

Our analysis indicates that citations are strongly and robustly correlated with improvements in the performance of patented inventions. For example, estimates from a QML Poisson model indicate that a 1 percent increase in yields is associated with a 0.76 percent increase in the number of citations, which implies a 9 percent increase compared with baseline citations.

We also investigate the existing evidence on the citations process, which has focused primarily on patent examiners, to investigate the influence of patent attorneys. This extension is important because attorneys account for the large majority of citations. We find that – similar to patent examiners – patent attorneys appear to have a group of favorite patents. Patent attorneys habitually cite a small group of early patents, which establish the patentability of corn hybrids. Five early patents for hybrid corn receive between 136 and 693 citations until 2005. This is a significantly larger share of highly cited patents compared with the overall population of citations in the NBER Patent Citation Data Set, in which 0.01 percent of all patents receive 136 citations or more.

In the case of hybrid corn, the correlation between citations and performance improvements is robust to controlling for the influence of early patents. In other industries, such as such as information technology and finance, these citations to early patents may be frequent enough to weaken the link between citations and performance. In USPTO subclass 705/35, for example, 5 early patents receive between 19 and 502 citations from patent issues between 1977 and 1985, which equals 185 citations for the average early patent. The first 100 patents (issued until 1998) received 181.3 citations on average, and the first 500 patents (issued until 2004) received 154.4 (Appendix Figure A6).

Complementary tests indicate that examiner-added citations are neither correlated with improvements in yields nor follow-on inventions. Instead patent examiners appear to focus almost entirely on identifying similarities in physical characteristics, independent of performance improvements. These results suggest that excluding examiner-added citations may improve the predictive power of citations.

Finally, our findings confirm an intuition in Hall, Jaffe, and Trajtenberg (2001) that self-citations can be a useful indicator for research programs of follow-on inventions in the same firm. Patents that cover inputs to follow-on inventions receive a minimum of 46 percent additional self-citations. This suggests that self-citations may be useful proxy for follow-on invention and internal research programs of firms which would otherwise be difficult to observe.

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

| | Mean | Std. Dev. | Median | Min | Max |
|---|---|---|---|---|---|
| Panel A: All patent-hybrid pairs (N=315) | | | | | |
| Citations | 8.314 | 46.492 | 2 | 0 | 693 |
| Self-citations | 4.435 | 24.019 | 1 | 0 | 386 |
| Citations by patents issued after 2000 | 7.460 | 41.826 | 2 | 0 | 621 |
| Examiner-added citations (after 2000) | 1.717 | 3.206 | 1 | 0 | 34 |
| Citations after 2000, excl. examiner-added | 5.743 | 41.533 | 0 | 0 | 618 |
| Increase in yields per acre (in %) | -0.608 | 4.191 | -0.505 | -26.611 | 12.338 |
| Increase in moisture (in %) | -0.276 | 5.272 | 0 | -16.746 | 20.976 |
| First patents | 0.016 | 0.125 | 0 | 0 | 1 |
| Year of application (1985 + *t*) | 13.079 | 2.649 | 13 | 0 | 17 |
| Breeder: Pioneer (N=142) | 0.451 | 0.498 | 0 | 0 | 1 |
| DeKalb (N=140) | 0.444 | 0.498 | 0 | 0 | 1 |
| Monsanto (N=14) | 0.044 | 0.206 | 0 | 0 | 1 |
| Asgrow (N=8) | 0.025 | 0.158 | 0 | 0 | 1 |
| Other (N=11) | 0.035 | 0.184 | 0 | 0 | 1 |
| Panel B: Controlling for insect resistance and herbicide tolerance (N=174) | | | | | |
| Citations | 9.402 | 55.144 | 2 | 0 | 693 |
| Self-citations | 3.954 | 13.630 | 1 | 0 | 125 |
| Citations by patents issued after 2000 | 7.862 | 47.908 | 2 | 0 | 621 |
| Examiner-added citations (after 2000) | 0.897 | 1.406 | 0 | 0 | 8 |
| Increase in yields per acre (in %) | -0.690 | 4.345 | -0.451 | -26.611 | 12.218 |
| Increase in moisture (in %) | -0.627 | 5.632 | -0.995 | -16.746 | 20.976 |
| Insect resistant | 0.017 | 0.131 | 0 | 0 | 1 |
| Herbicide tolerant | 0.011 | 0.107 | 0 | 0 | 1 |
| Follow-on hybrid, insect resistant | 0.333 | 0.473 | 0 | 0 | 1 |
| Follow-on hybrid, herbicide tolerant | 0.224 | 0.418 | 0 | 0 | 1 |
| First patents | 0.023 | 0.150 | 0 | 0 | 1 |
| Year of application (1985 + *t*) | 12.569 | 3.117 | 13 | 0 | 17 |
| Breeder: Pioneer (N=140) | 0.805 | 0.398 | 1 | 0 | 1 |
| DeKalb (N=18) | 0.103 | 0.305 | 0 | 0 | 1 |
| Monsanto (N=14) | 0.080 | 0.273 | 0 | 0 | 1 |
| Other (N=2) | 0.011 | 0.107 | 0 | 0 | 1 |

*Notes:* Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*. *(Forward) Citations* measures the number of patents that cite a patent as relevant prior art. *Self-citations* measure the sum of self-citations to a patent - hybrid pair. *Citations by patents issued after 2000* counts citations by patents that were issued after 2000. *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art; examiner-added citations are only observable for patents that were issued after 2000. *Increase in yields per acre* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the water content of a corn hybrid at harvest relative to the highest-yielding comparison hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). *Breeder* refers to the patent assignee. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid.

TABLE 2 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS TO PATENT - HYBRID PAIRS

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Yields | 0.764*** | 0.788*** | 0.875** | 0.867* |
| | (0.263) | (0.277) | (0.437) | (0.460) |
| Moisture | | -0.076 | -0.060 | -0.065 |
| | | (0.148) | (0.195) | (0.196) |
| Insect resistant | | | | -10.62 |
| | | | | (8.400) |
| Herbicide tolerant | | | | -9.566 |
| | | | | (8.160) |
| Insect resistant follow-on hybrid | | | | 4.301** |
| | | | | (1.963) |
| Herbicide tolerant follow-on hybrid | | | | 6.993*** |
| | | | | (2.256) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | |
| N | 315 | 315 | 174 | 174 |
| Mean citations | 8.314 | 8.314 | 8.314 | 8.314 |
| R-squared | 0.628 | 0.628 | 0.849 | 0.867 |
| Year FE | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. Year fixed effects control for the year of the patent application (1985 + t). All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 3 – HIGHLY-CITED PATENTS

| Patent number | Title | Applied | Issued | Assignee | Hybrid | Increase in yields (in %) | Total Citations | Citations after 2000 | Examiner-added citations (after 2000) |
|---|---|---|---|---|---|---|---|---|---|
| 4,607,453 | Hybrid corn plants with improved standability | Feb 21, 1985 | Aug 26, 1986 | DeKalb | *dk672* | -1.699 | 136 | 77 | 0 |
| 4,629,819 | Novel hybrid corn plant | Apr 26, 1985 | Dec 16, 1986 | DeKalb | *dk524* | 6.641 | 137 | 77 | 0 |
| 4,731,499 | Hybrid corn plant and seed | Jan 29, 1987 | Mar 15, 1988 | Pioneer | *3790* | 2.810 | 693 | 621 | 3 |
| 4,737,596 | Hybrid corn plant and seed | Jan 29, 1987 | Apr 12, 1988 | Pioneer | *3471* | -2.868 | 139 | 77 | 0 |
| 6,433,261 | Inbred corn plant 89AHD12 and seeds thereof | Jan 8, 2001 | Aug 13, 2002 | DeKalb | *8012685* | 2.573 | 390 | 390 | 6 |

*Notes:* Pioneer refers to Pioneer Hi-Bred International; DeKalb refers to DeKalb Genetics. *Increase in yields per acre* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *(Forward) Citations* measures the number of patents that cite a patent as relevant prior art. *Citations by patents issued after 2000* counts citations by patents that were issued after 2000. *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art; examiner-added citations are only observable for patents that were issued after 2000

TABLE 4 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS (COLUMNS 1, 3-4), FORWARD CITATIONS AFTER 2000, EXCLUDING EXAMINER-ADDED CITATIONS (COLUMNS 2) AND SELF-CITATIONS (COLUMNS 5-6) TO PATENT - HYBRID PAIRS

| | All citations | All citations after 2000, excl. examiner-added | All citations (3-4) | | Self-citations (5-6) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Yields | 0.751***<br>(0.261) | 0.743***<br>(0.265) | 0.875**<br>(0.437) | 0.867*<br>(0.460) | 0.054<br>(0.049) | 0.025<br>(0.038) |
| Moisture | -0.017<br>(0.116) | -0.095<br>(0.117) | -0.060<br>(0.195) | -0.065<br>(0.196) | -0.052<br>(0.073) | -0.078<br>(0.069) |
| Insect resistant | | | | -10.62<br>(8.400) | | -0.888<br>(3.701) |
| Herbicide tolerant | | | | -9.566<br>(8.160) | | -2.391<br>(3.367) |
| Insect resistant follow-on hybrid | | | | 4.301**<br>(1.963) | | 2.063**<br>(0.851) |
| Herbicide tolerant follow-on hybrid | | | | 6.993***<br>(2.256) | | 3.693***<br>(0.912) |
| First patents | 36.34***<br>(3.935) | 29.92***<br>(4.017) | 36.54***<br>(7.052) | 42.04***<br>(8.281) | 19.24***<br>(1.386) | 21.65***<br>(1.670) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | | |
| N | 315 | 315 | 174 | 174 | 174 | 174 |
| Mean citations | 8.314 | 5.743 | 9.402 | 9.402 | 4.435 | 4.435 |
| R-squared | 0.802 | 0.818 | 0.849 | 0.867 | 0.639 | 0.706 |
| Year FE | YES | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair (columns 1, 3-4); examiner-added citations are only observable for patents that were issued after 2000. *Self-citations* measure the sum of self-citations to a patent - hybrid pair (columns 5-6). The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). The dummy variable *highly-cited* is a linear combination of the year fixed effects in the reduced sample of 174 observations (column 3-4), therefore the coefficient estimates are identical to the ones reported in Table 2, columns 3-4. All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; “R-squared” is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 5 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS AFTER 2000 (COLUMNS 1-3) AND EXAMINER-ADDED CITATIONS (COLUMNS 4-6) TO PATENT - HYBRID PAIRS

| | All citations after 2000 (1-3) | | | Examiner-added citations (4-6) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Yields | 0.765*** | 0.906** | 0.910** | 0.086 | 0.014 | 0.017 |
| | (0.258) | (0.430) | (0.455) | (0.081) | (0.028) | (0.029) |
| Moisture | -0.0491 | -0.137 | -0.140 | 0.011 | -0.014 | -0.014 |
| | (0.103) | (0.161) | (0.162) | (0.036) | (0.016) | (0.015) |
| Insect resistant | | | -9.309 | | | -0.088 |
| | | | (7.182) | | | (0.805) |
| Herbicide tolerant | | | -8.131 | | | -0.350 |
| | | | (7.140) | | | (0.732) |
| Insect resistant follow-on hybrid | | | 3.482** | | | -0.022 |
| | | | (1.675) | | | (0.240) |
| Herbicide tolerant follow-on hybrid | | | 5.891*** | | | -0.083 |
| | | | (2.010) | | | (0.238) |
| First patents | 32.58*** | 26.12*** | 30.88*** | 1.335 | -13.74*** | -12.87*** |
| | (3.828) | (5.988) | (7.073) | (1.143) | (1.474) | (1.398) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | | |
| N | 315 | 174 | 174 | 315 | 174 | 174 |
| Mean citations | 7.460 | 7.862 | 7.862 | 1.717 | 0.897 | 0.897 |
| R-squared | 0.767 | 0.808 | 0.830 | 0.112 | 0.148 | 0.149 |
| Year FE | YES | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations by patents issued after 2000* counts citations by patents that were issued after 2000 (columns 1-3). *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art (columns 4-6); examiner-added citations are only observable for patents that were issued after 2000. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 6 – PATENTS AND CLAIMS BY BREEDER AND ATTORNEY

| Breeder | Attorney | # of patents | Average # of claims |
|---|---|---|---|
| Pioneer | Pioneer; IP counsel | 117 | 15.7 |
| | McKee, Voorhees & Sease | 23 | 23.2 |
| | Saidman, Sterne, Kessler & Goldstein | 2 | 5.0 |
| Dekalb | Arnold, White & Durkee | 62 | 36.4 |
| | Fulbright & Jaworski | 46 | 28.0 |
| | Knuth, Richardson & Monroe | 1 | 5.0 |
| | Sughrue, Mion, Zinn, Macpeak & Seas | 1 | 3.0 |
| Asgrow | Fulbright & Jaworski | 8 | 29.8 |
| Rustica Prograin Genetique | Patterson, Thuente, Skaar & Christensen | 3 | 50.0 |
| Monsanto | Fulbright & Jaworski | 2 | 29.0 |
| Kleinwanzlebener Saatzucht | Townsend, Townsend & Crew | 2 | 9.5 |
| Euralis | Patterson, Thuente, Skaar & Christensen | 1 | 31.0 |
| Sandoz | Marcus-Wyner & Norris | 1 | 16.0 |
| All patents | | 269 | 24.0 |

*Notes:* Data include 269 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*. Data on patent attorneys is available at http://patft.uspto.gov.

TABLE 7A – EXAMPLE OF AN EXAMINER'S SEARCH REPORT

**Search History**

**DATE: Sunday, October 02, 2005** Printable Copy Create Case

DB=PGPB,USPT; PLUR=YES; OP=OR

| Set Name side by side | Query | Hit Count | Set Name result set |
|---|---|---|---|
| L18 | l12 and L17 | 10 | L18 |
| L17 | L16 and l11 | 11 | L17 |
| L16 | L14 and l9 | 18 | L16 |
| L15 | l8 and L14 | 2 | L15 |
| L14 | L6 and l7 | 175 | L14 |
| L13 | ((grey or gray) adj leaf adj spot) near10 (tolera$ or resist$) | 496 | L13 |
| L12 | cob near10 red | 531 | L12 |
| L11 | (ear or position) near10 horizontal | 181431 | L11 |
| L10 | silk near10 ((pale or light) adj yellow) | 18 | L10 |
| L9 | glume near10 purple | 230 | L9 |
| L8 | anther near10 ((pale or light) adj yellow) | 192 | L8 |
| L7 | (leaf or leaves) near10 (dark adj green) | 2705 | L7 |
| L6 | anthocyanin near10 (faint or light) | 606 | L6 |
| L5 | L4 not l3 | 1 | L5 |
| L4 | ge2085580 or ge514284 | 2 | L4 |
| L3 | 33y45 | 1 | L3 |
| L2 | L1 and (800/320.1).ccls. | 15 | L2 |
| L1 | colbert.in. near2 terry.in. | 15 | L1 |

END OF SEARCH HISTORY

TABLE 7B – EXCERPT OF SEARCH RESULTS

☐ 5. Document ID: US 6759577 B1

L18: Entry 5 of 10 File: USPT Jul 6, 2004

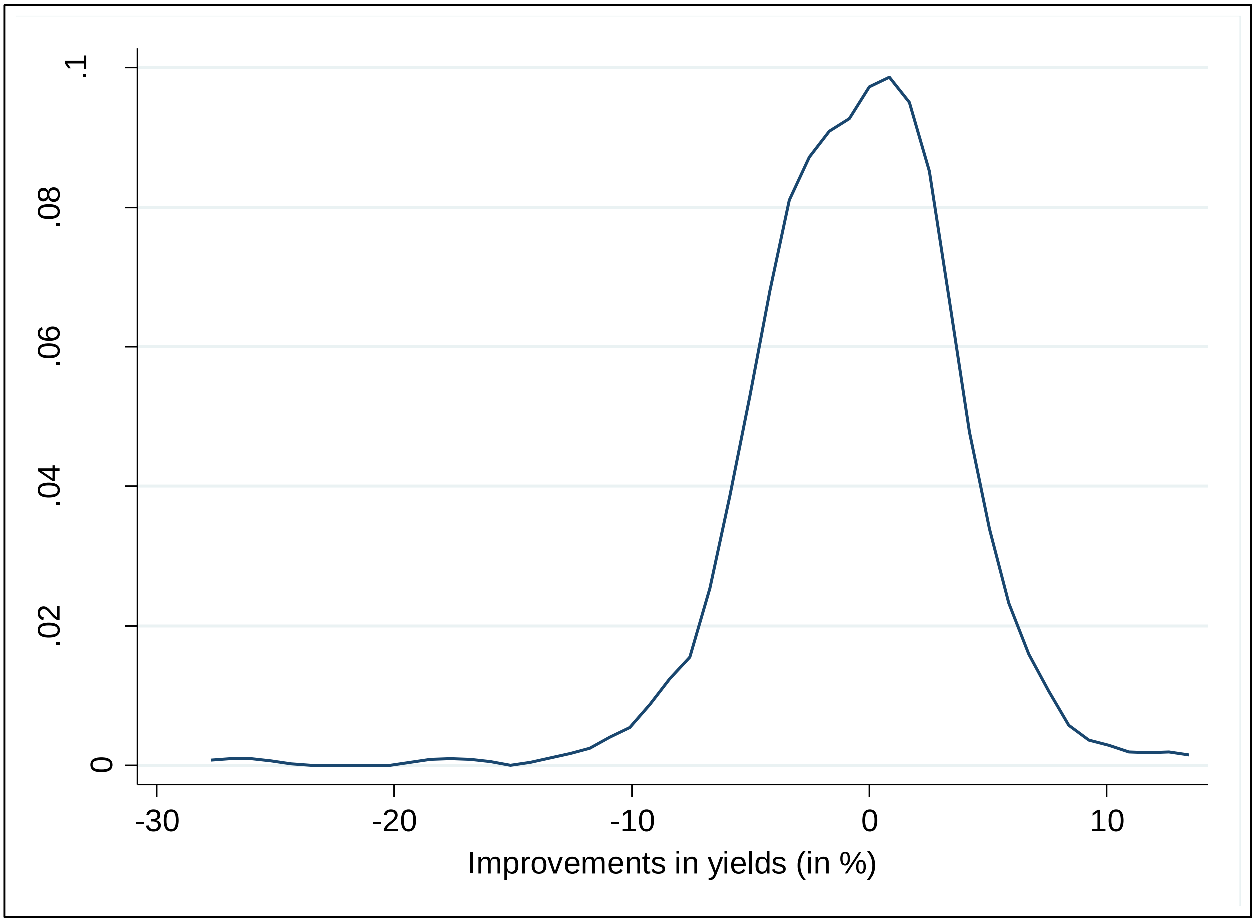
US-PAT-NO: 6759577
DOCUMENT-IDENTIFIER: US 6759577 B1
** See image for Certificate of Correction **

TITLE: Hybrid maize plant and seed 37Y15

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

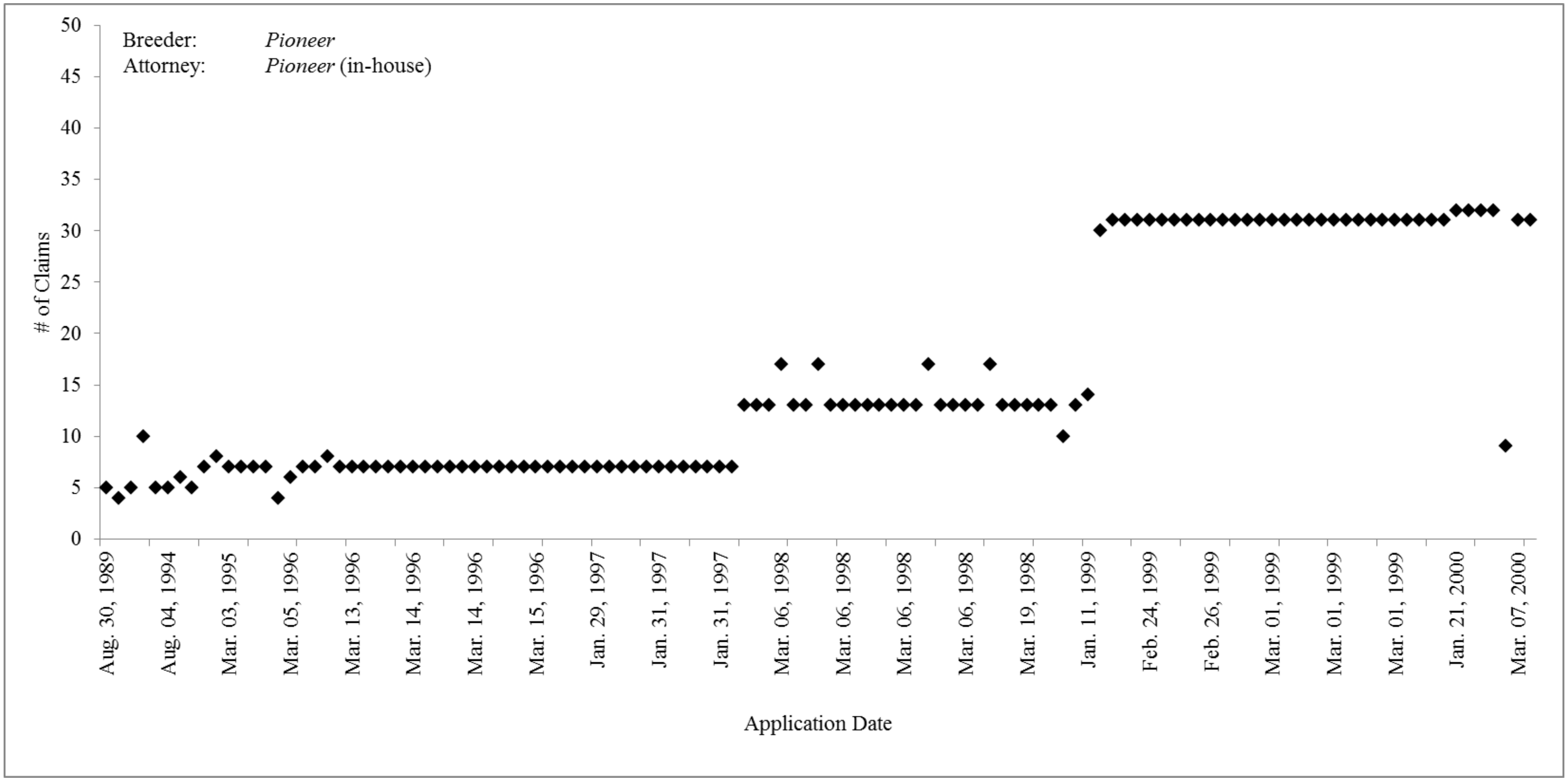
*Notes:* Information on examiner's search reports is available at the USPTO's Patent Application Information Retrieval portal: http://portal.uspto.gov/pair/PublicPair. Table 7A shows the examiner's search history for US7,087,821. Table 7B shows information for one of the 10 patents that resulted from the search 'L18' in Table 7A. This is the only examiner-added citation to US7,087,821.

FIGURE 1 – IMPROVEMENTS IN YIELDS, ALL UTILITY PATENTS FOR HYBRID CORN, 1986-2005




*Notes:* Improvements in corn yields for 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* (available at www.uspto.gov). Omitting 5 highly-cited patents with 136 to 390 citations from the sample produces no noticeable differences in the distribution of yields; yields for these highly-cited patents are listed in Table 3. Improvements in corn yields are calculated by comparing the yield of the new hybrid with the highest yield of comparison hybrids. Yields are based on field trial data, which breeders report on patent applications.

FIGURE 2 – NUMBER OF CLAIMS INCLUDED IN THE PATENT BY APPLICATION DATE




*Notes:* Data include 117 US utility patents assigned to Pioneer with Pioneer (in-house) as the attorney. If 2 patents have the same application date, the patent with the lower patent number appears first. Data on patent attorneys is available at http://patft.uspto.gov

**SUPPLEMENTAL APPENDIX – FOR ONLINE PUBLICATION ONLY**

*A.1. Other indicators of patent quality: foreign patent family members*

We also examined information on the size of the "patent family," the number of countries in which an invention is patented, as an alternative measure for the quality of patents. Intuitively, inventors are more likely to incur the costs of patenting an invention in more countries if the patent is more valuable and has a larger market (Putnam 1996, and Gambardella et al. 2008). For crops, and other types of biological inventions, however, this measure may be downward biased because biological inventions cannot be patented in all countries. The European Patent Office (EPO), for example, has traditionally not granted patents for hybrid corn. On January 21, 2014, the EPO denied Monsanto's patent application No. 07871115 for "Methods for Hybrid Corn Seed Production and Compositions produced therefrom."[1] In addition, breeders' may choose not to apply for patents for GMOs in countries where GMOs are subject to strict regulation, which limits the marketability of GM hybrids in these countries. The European Union, for example, is subject to particularly strict regulation (Davison 2010). For example, Regulation (EC) No 1829/2003 of the European Parliament and Council (issued September 22, 2003) specifies that "in order to protect human and animal health, food and feed consisting of, containing or produced from genetically modified organisms (…) should undergo a safety assessment through a Community procedure before being placed on the market within the Community." However, EU member countries might impose even stricter rules. On April 14, 2009, Germany's Federal Office of Consumer Protection and Food Safety forbid farmers to plant corn hybrids that carry Monsanto's trait MON810 for insect resistance.[2] Quoting a report of the European Food Safety Authority from October 29, 2008, Monsanto appealed this decision arguing that MON810 had not been rigorously shown to carried no documented risks for food or feed. On May 4, 2009, the Administrative Court of Braunschweig, Germany denied Monsanto's appeal arguing that a ban is legal as long as new or additional information indicate that people or animals might be harmed even in the absence of definite scientific proof.[3] We find that none of the 269 US patents issued for hybrid corn had a foreign patent family member.[4]

[1] EPO case number T 2362/10 (European Case Law Identifier: ECLI:EP:BA:2014:T236210.20140121).
[2] A similar ban was also imposed by Austria, France, Greece, Hungary and Italy (Davison 2010).
[3] Administrative court Braunschweig (Germany), case number 2 B 111/09.
[4] Data on patent families are available from the EPO at http://worldwide.espacenet.com, accessed on June 2014.

*A.2. Erroneous citations*

We also examine the title and abstract of all 1,157 citing patents to check whether citations may be added erroneously as a result of typos or other types of errors. For example, US6,518,986 for “Method and apparatus for providing an on-screen guide for a multiple channel broadcasting system” (issued February 11, 2003, assigned to Sony Corporation) cites US6,114,614 for “Hybrid maize plant and seed 33B50” as relevant prior art. The issue date and inventor names that are listed on Sony’s patent, are, however, different from the issue date and inventor names of US6,114,614. Information on the issue date and the name of the inventors indicates that the citation is “off” in the fourth digit of the patent number: US6,111,614 for “Method and apparatus for displaying an electronic menu having components with differing levels of transparency” issued on August 29, 2000 and assigned to Sony Corporation. Checking all 1,157 patents reveals 16 erroneous citations (1.4 percent). All of these erroneous citations are due to typographical errors; excluding them from the analysis leaves the estimates substantially unchanged.

TABLE A1 – EXAMPLE OF HYBRID CORN TRAITS REPORTED IN FIELD TRIALS

| Traits | Description | # of Observations |
|---|---|---|
| Traits that farmers use in income calculations | | |
| *Yields* | Yield of the grain at harvest in bushels per acre | 315 |
| *Harvest moisture* | Actual percentage moisture of grain at harvest | 315 |
| Traits that farmers do NOT use in income calculations | | |
| *Not stalk lodged* | Plants that did not stalk lodge (stalk breakage) | 219 |
| *Dry-down* | Rate at which acceptable harvest moisture is reached | 114 |
| *Seedling vigor* | Vegetative growth after emergence at seedling stage | 31 |
| *Not root lodged* | Stalks not root lodged at harvest | n/a |
| *Early stand* | Number of plants that emerge | n/a |
| *Plant height* | Height of the plant from ground to tip of the tassel | n/a |
| *Ear height* | Height from ground to highest placed developed ear | n/a |
| *Not barren* | Plants that were not barren (lack ears) | n/a |
| *Stay green* | Plant health near time of black layer formation | n/a |

*Notes:* Included are all traits reported in field trial data included in DeKalb’s patent US4,629,819 for hybrid dk524. *Yield* and *moisture* are main traits that farmers use to calculate gross income. A typical gross income equation takes the current market price per bushel of corn as given and assumes a drying cost of $0.02 per percentage point moisture above 15.5 percent (e.g., US6,835,877 for Pioneer’s hybrid 34m94). Pioneer, for example, provides product performance information in terms of individual plot reports for various regions on its website and provides the following explanation on how gross income per acre is derived: “Income per acre is calculated based on a $0.04 dry down cost and 15.00% moisture. The following market values are currently applied for Corn: Conventional = $3.5/bushel price.” (available at www.pioneer.com; accessed Dec. 2015). *n/a* refers non-consistent reported data. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A2 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS TO PATENT - HYBRID PAIRS, CONTROLLING FOR ADDITIONAL TRAITS

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Yields | 0.592** | 0.163* | 0.353** | 0.193 | 0.418 |
| | (0.245) | (0.084) | (0.168) | (0.148) | (0.277) |
| Moisture | -0.029 | -0.083 | 0.009 | -0.109 | 0.057 |
| | (0.208) | (0.063) | (0.116) | (0.149) | (0.234) |
| Stalk lodging | 0.071 | | 0.016 | | 0.009 |
| | (0.324) | | (0.135) | | (0.253) |
| Dry-down | | -0.384 | 0.518 | | 0.330 |
| | | (0.382) | (0.766) | | (0.939) |
| Vigor | | | | 0.000 | 0.004 |
| | | | | (0.062) | (0.099) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | |
| N | 219 | 114 | 42 | 31 | 26 |
| Mean citations | 10.132 | 3.123 | 3.619 | 3.516 | 3.923 |
| R-squared | 0.653 | 0.158 | 0.190 | 0.133 | 0.207 |
| Year FE | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Stalk lodging* measures the relative percentage of plants that did not stalk lodge of the patented hybrid to the highest-yielding comparison hybrid. *Dry-down* measures the relative rate at which the patented hybrid will reach acceptable harvest moisture to the highest-yielding comparison hybrid (a high score indicates a hybrid that dies relatively fast). *Vigor* measures the relative rate of the amount of vegetative growth after emergence at the seedling stage of the patented hybrid to the highest-yielding comparison hybrid (a high score indicates better vigor). Year fixed effects control for the year of the patent application (1985 + t). All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A3 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS (COLUMNS 1-3), SELF-CITATIONS (COLUMN 4) AND EXAMINER-ADDED CITATIONS (COLUMN 5) TO PATENT - HYBRID PAIRS, CONTROLLING FOR THE SIGNIFICANCE LEVEL OF DIFFERENCES IN YIELDS AND MOISTURE

| | | All citations (1-4) | | Self-citations | Examiner-added |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Yields | 0.681** | 0.926*** | 1.130** | 0.092 | 0.012 |
| | (0.284) | (0.277) | (0.458) | (0.060) | (0.037) |
| Moisture | 0.015 | -0.011 | -0.066 | -0.059 | -0.006 |
| | (0.125) | (0.116) | (0.199) | (0.070) | (0.016) |
| Insect resistant | | | -9.476 | -1.274 | -0.065 |
| | | | (7.225) | (3.629) | (0.782) |
| Herbicide tolerant | | | -9.126 | -2.361 | -0.313 |
| | | | (8.349) | (3.303) | (0.706) |
| Insect resistant follow-on hybrid | | | 4.138** | 2.035** | -0.028 |
| | | | (1.936) | (0.844) | (0.242) |
| Herbicide tolerant follow-on hybrid | | | 7.050*** | 3.633*** | -0.073 |
| | | | (2.209) | (0.905) | (0.240) |
| First patents | | 38.36*** | 41.60*** | 21.57*** | -13.81*** |
| | | (3.569) | (7.623) | (1.820) | (1.467) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | |
| N | 315 | 315 | 174 | 174 | 174 |
| Mean citations | 8.314 | 8.314 | 9.402 | 3.954 | 0.897 |
| R-squared | 0.619 | 0.806 | 0.874 | 0.706 | 0.147 |
| Year FE | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair (columns 1-3). *Self-citations* measure the sum of self-citations to a patent - hybrid pair (column 4). *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art (column 5); examiner-added citations are only observable for patents that were issued after 2000. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. The variable *yields* is set to zero if the difference between the patented hybrid and the comparison hybrid is not significant at the 1% level. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. The variable *moisture* is set to zero if the difference between the patented hybrid and the comparison hybrid is not significant at the 1% level. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A4 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS (COLUMNS 1-3), SELF-CITATIONS (COLUMN 4) AND EXAMINER-ADDED CITATIONS (COLUMN 5) TO PATENT - HYBRID PAIRS, CONTROLLING FOR MULTIPLE PATENTS PER HYBRID AND MULTIPLE HYBRIDS PER PATENT

| | | All citations (1-4) | | Self-citations | Examiner-added |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Yields | 0.818*** | 0.728*** | 0.880* | 0.028 | 0.014 |
| | (0.317) | (0.267) | (0.464) | (0.041) | (0.021) |
| Moisture | -0.153 | -0.058 | -0.043 | -0.076 | -0.015 |
| | (0.164) | (0.119) | (0.201) | (0.068) | (0.015) |
| Insect resistant | | | -10.62 | -0.896 | -0.073 |
| | | | (8.340) | (3.697) | (0.803) |
| Herbicide tolerant | | | -9.355 | -2.377 | -0.358 |
| | | | (8.128) | (3.367) | (0.730) |
| Insect resistant follow-on hybrid | | | 3.767* | 2.099** | -0.145 |
| | | | (1.987) | (0.858) | (0.263) |
| Herbicide tolerant follow-on hybrid | | | 8.008*** | 3.683*** | 0.048 |
| | | | (2.417) | (0.953) | (0.262) |
| First patents | | 36.72*** | 39.16*** | 20.17*** | -10.58*** |
| | | (4.062) | (8.872) | (2.204) | (1.108) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | |
| N | 315 | 315 | 174 | 174 | 174 |
| Mean citations | 8.314 | 8.314 | 9.402 | 3.954 | 0.897 |
| R-squared | 0.633 | 0.806 | 0.869 | 0.706 | 0.201 |
| Year FE | YES | YES | YES | YES | YES |
| > 1 patent FE | YES | YES | YES | YES | YES |
| > 1 hybrid FE | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair (columns 1-3). *Self-citations* measure the sum of self-citations to a patent - hybrid pair (column 4). *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art (column 5); examiner-added citations are only observable for patents that were issued after 2000. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). The control variable *> 1 patent* equals 1 if the same hybrid is the subject of more than 1 utility patent. The control variable *> 1 hybrid* equals 1 if the same utility patent covers more than 1 hybrid. All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A5 – POISSON, DEPENDENT VARIABLE IS FORWARD CITATIONS (COLUMNS 1-3), SELF-CITATIONS (COLUMN 4) AND EXAMINER-ADDED CITATIONS (COLUMN 5) TO PATENT - HYBRID PAIRS, CONTROLLING FOR THE GRANT YEAR

| | All citations (1-4) | | | Self-citations | Examiner-added |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Yields | 0.907*** | 0.802*** | 0.892* | 0.021 | 0.008 |
| | (0.319) | (0.267) | (0.464) | (0.041) | (0.025) |
| Moisture | -0.085 | -0.013 | 0.041 | -0.027 | -0.012 |
| | (0.142) | (0.111) | (0.200) | (0.067) | (0.016) |
| Insect resistant | | | -14.73* | -2.664 | -0.043 |
| | | | (8.096) | (3.493) | (0.782) |
| Herbicide tolerant | | | -12.09 | -3.812 | -0.227 |
| | | | (8.324) | (3.093) | (0.785) |
| Insect resistant follow-on hybrid | | | 4.587** | 2.345*** | 0.001 |
| | | | (2.009) | (0.832) | (0.238) |
| Herbicide tolerant follow-on hybrid | | | 6.735*** | 3.378*** | -0.120 |
| | | | (2.233) | (0.928) | (0.245) |
| First patents | | 37.47*** | 41.96*** | 21.21*** | -12.64*** |
| | | (4.047) | (8.067) | (1.643) | (1.456) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | |
| N | 315 | 315 | 174 | 174 | 174 |
| Mean citations | 8.314 | 8.314 | 9.402 | 3.954 | 0.897 |
| R-squared | 0.629 | 0.805 | 0.867 | 0.690 | 0.126 |
| Grant Year FE | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair (columns 1-3). *Self-citations* measure the sum of self-citations to a patent - hybrid pair (column 4). *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art (column 5); examiner-added citations are only observable for patents that were issued after 2000. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year the patent was granted. All specifications estimate the average marginal effects of unconditional fixed effects Poisson regressions; "R-squared" is the pseudo R-squared of the equivalent regression that estimates Poisson coefficients. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A6 – OLS, DEPENDENT VARIABLE IS FORWARD CITATIONS TO PATENT - HYBRID PAIRS

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Yields | 0.653** | 0.668** | 0.598 | 0.571 |
| | (0.301) | (0.306) | (0.438) | (0.468) |
| Moisture | | -0.049 | -0.053 | -0.044 |
| | | (0.080) | (0.052) | (0.054) |
| Insect resistant | | | | -3.758 |
| | | | | (3.035) |
| Herbicide tolerant | | | | -1.447 |
| | | | | (1.401) |
| Insect resistant follow-on hybrid | | | | 1.348 |
| | | | | (0.873) |
| Herbicide tolerant follow-on hybrid | | | | 2.541* |
| | | | | (1.422) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | |
| N | 315 | 315 | 174 | 174 |
| Mean citations | 8.314 | 8.314 | 9.402 | 9.402 |
| R-squared | 0.554 | 0.554 | 0.706 | 0.707 |
| Year FE | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. Year fixed effects control for the year of the patent application (1985 + t). Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A7 – OLS, DEPENDENT VARIABLE IS FORWARD CITATIONS (COLUMNS 1, 3-4), FORWARD CITATIONS AFTER 2000, EXCLUDING EXAMINER-ADDED CITATIONS (COLUMNS 2) AND SELF-CITATIONS (COLUMNS 5-6) TO PATENT - HYBRID PAIRS

| | All citations (1-4) | All citations after 2000, excl. examiner-added | All citations (3-4) | | Self-citations (5-6) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Yields | 0.510** | 0.419* | 0.598 | 0.571 | 0.056 | -0.002 |
| | (0.245) | (0.235) | (0.438) | (0.468) | (0.047) | (0.044) |
| Moisture | -0.031 | -0.0453 | -0.053 | -0.044 | -0.033 | -0.028 |
| | (0.046) | (0.032) | (0.052) | (0.054) | (0.041) | (0.0414) |
| Insect resistant | | | | -3.758 | | 0.169 |
| | | | | (3.035) | | (0.906) |
| Herbicide tolerant | | | | -1.447 | | -0.184 |
| | | | | (1.401) | | (0.791) |
| Insect resistant follow-on hybrid | | | | 1.348 | | 0.954 |
| | | | | (0.873) | | (0.624) |
| Herbicide tolerant follow-on hybrid | | | | 2.541* | | 3.432*** |
| | | | | (1.422) | | (1.028) |
| First patents | 384.5*** | 381.3*** | 134.0*** | 135.0*** | 123.6*** | 124.8*** |
| | (1.139) | (0.778) | (1.718) | (1.919) | (0.591) | (0.791) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | | |
| N | 315 | 315 | 174 | 174 | 174 | 174 |
| Mean citations | 8.314 | 5.743 | 9.402 | 9.402 | 3.954 | 3.954 |
| R-squared | 0.766 | 0.725 | 0.706 | 0.707 | 0.939 | 0.954 |
| Year FE | YES | YES | YES | YES | YES | YES |

*Notes:* The dependent variable *citations* measures the sum of forward citations to a patent - hybrid pair (columns 1-4). *Self-citations* measure the sum of self-citations to a patent - hybrid pair (columns 5-6). The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). The dummy variable *highly-cited* is a linear combination of the year fixed effects in the reduced sample of 174 observations (column 3-4), therefore the coefficient estimates are identical to the ones reported in Table A6, columns 3-4. Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE A8 – OLS, DEPENDENT VARIABLE IS FORWARD CITATIONS AFTER 2000 (COLUMNS 1-3) AND EXAMINER-ADDED CITATIONS (COLUMNS 4-6) TO PATENT - HYBRID PAIRS

| | All citations after 2000 (1-3) | | | Examiner-added citations (4-6) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Yields | 0.506** | 0.591 | 0.565 | 0.087* | 0.010 | 0.011 |
| | (0.241) | (0.431) | (0.460) | (0.045) | (0.020) | (0.020) |
| Moisture | -0.033 | -0.056 | -0.047 | 0.012 | -0.011 | -0.011 |
| | (0.046) | (0.052) | (0.054) | (0.033) | (0.014) | (0.014) |
| Insect resistant | | | -3.725 | | | -0.061 |
| | | | (2.987) | | | (0.639) |
| Herbicide tolerant | | | -1.465 | | | -0.244 |
| | | | (1.393) | | | (0.472) |
| Insect resistant follow-on hybrid | | | 1.279 | | | -0.026 |
| | | | (0.866) | | | (0.237) |
| Herbicide tolerant follow-on hybrid | | | 2.542* | | | -0.072 |
| | | | (1.408) | | | (0.244) |
| First patents | 384.5*** | 74.49*** | 75.46*** | 3.258*** | -1.749*** | -1.774*** |
| | (1.134) | (2.035) | (2.195) | (0.858) | (0.367) | (0.362) |
| Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10 | | | | | | |
| N | 315 | 174 | 174 | 315 | 174 | 174 |
| Mean citations | 7.460 | 7.862 | 7.862 | 1.717 | 0.897 | 0.897 |
| R-squared | 0.721 | 0.624 | 0.625 | 0.094 | 0.324 | 0.325 |
| Year FE | YES | YES | YES | YES | YES | YES |

*Notes:* The dependent variable c*itations by patents issued after 2000* counts citations by patents that were issued after 2000 (columns 1-3). *Examiner-added citations (after 2000)* counts citations that the USPTO's examiner added to the list of relevant prior art (columns 4-6); examiner-added citations are only observable for patents that were issued after 2000. The variable *yields* measures the improvement in yields (in percent) over existing hybrids. In case of multiple comparisons in the patent, we selected the highest-yielding comparison hybrid. *Moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* equals 1 if the patented hybrid is insect resistant while the comparison hybrid is not. *Herbicide tolerant* equals 1 if the patented hybrid is herbicide tolerant while the comparison hybrid is not. *Insect resistant follow-on hybrid* equals 1 if a genetically modified hybrid, which shares the same base genetics, but is also insect resistant, is introduced by the same breeder as a follow-on hybrid. *Herbicide tolerant follow-on hybrid* equals 1 if a genetically-modified hybrid, which shares the same base genetics, but is also herbicide tolerant, is introduced by the same breeder as a follow-on hybrid. The variable *first patents* is an indicator for the first four patents that the USPTO issued for hybrid corn (US4,607,453; US4,629,819; US4,731,499; US 4,737,596 ); it also captures one patent (US6,433,261) that later patents cite along with US4,731,499 (see Table 3 for a detailed description). Year fixed effects control for the year of the patent application (1985 + t). Data include 315 patents – hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize.*

TABLE A9 – SHARE OF RENEWED PATENTS BY TIME OF RENEWAL

| Time of renewal | 4 years | 8 years | 12 years |
|---|---|---|---|
| Patents issued 1986 – 2002 (N=233) | 98.3% | 97.9% | 97.4% |
| Patents issued 2003 – 2005 (N=36) | 100.0% | 100.0% | n/a |
| All patents (N=269) | 98.5% | 98.1% | n/a |

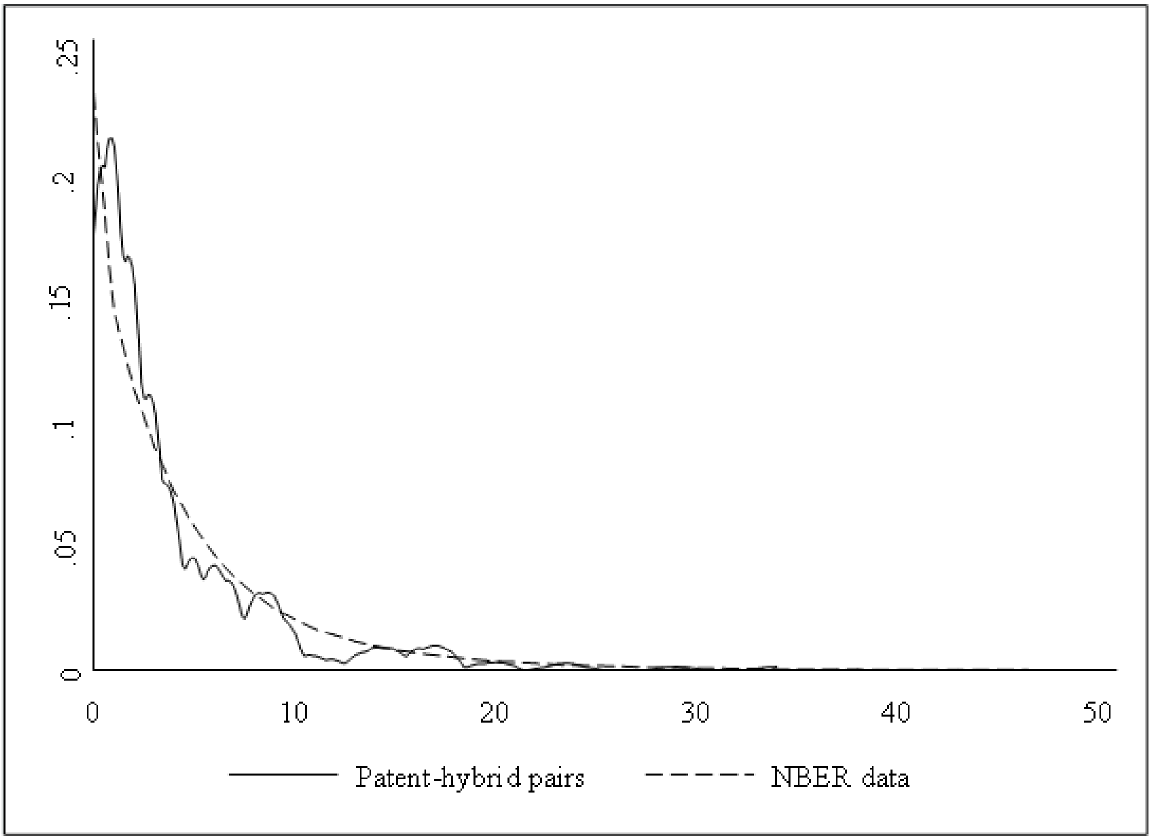
*Notes:* Data include 269 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*. Data on patent renewals is available at https://ramps.uspto.gov/eram/patentMaintFees.do and was accessed in 2014. The decision on patent renewal 12 years after issue can therefore not be observe for patents issued after 2002.

TABLE A10 - FIELD TRIAL DATA

| Institution conducting the Field Trials | Name of the Field Trial | Years |
|---|---|---|
| University of Kentucky, College of Agriculture, Agricultural Experiment Station, Department of Agronomy | Hybrid Corn Performance Test | 1996 – 2005 |
| University of Wisconsin-Madison, College of Agricultural and Life Sciences | Corn Hybrid Performance Trial | 1996 – 2005 |
| Prince Edward Island, Department of Agriculture, Fisheries and Aquaculture, Agricultural Resources Division | Corn Guide to Hybrid Selection | 2006 |
| Ontario Corn Committee | Hybrid Corn Performance Trial | 2001 – 2003 |

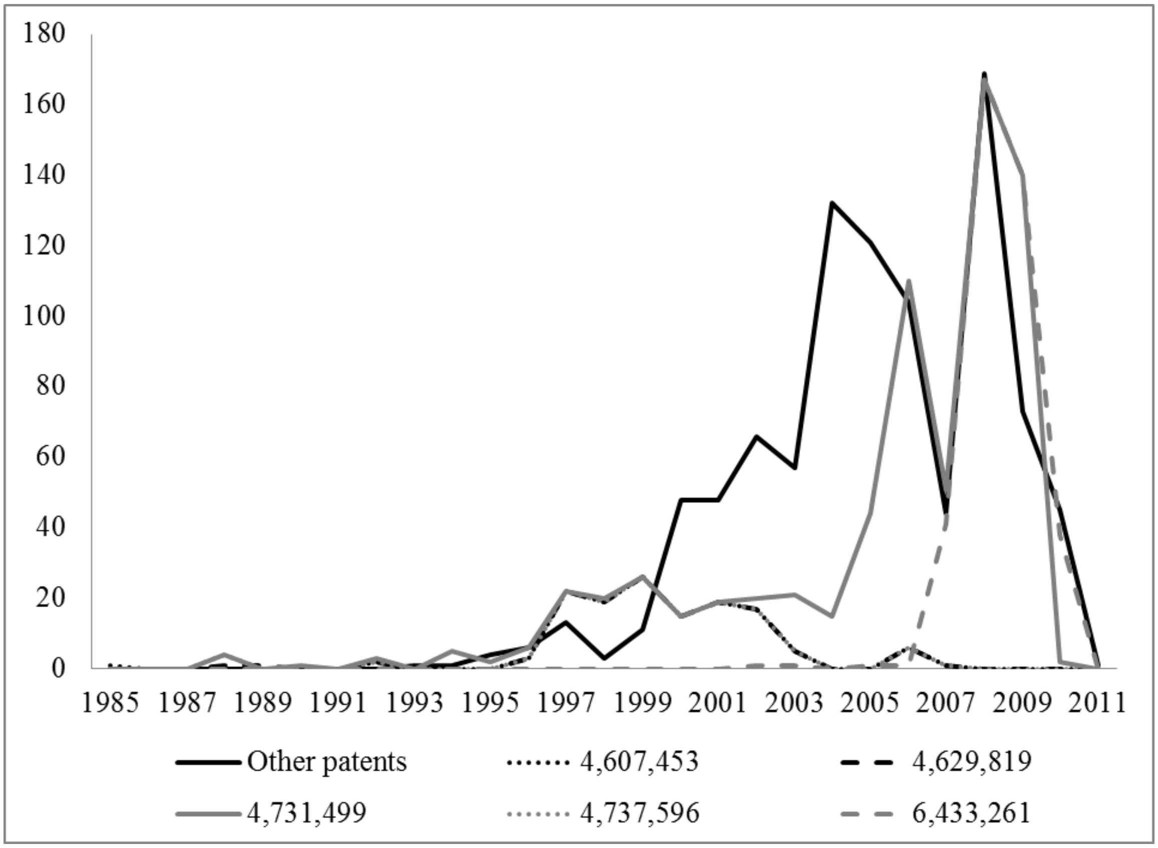
*Notes*: Field trial reports are available from the following website: http://www.ca.uky.edu/cornvarietytest/; http://corn.agronomy.wisc.edu/HT/Default.aspx; http://www.gov.pe.ca/photos/original/af_06cornguide.pdf; http://www.gocorn.net/v2006/CornReports/2001cornreport/2001performancetrials.html; http://www.gocorn.net/v2006/CornReports/2002cornreport/2002performancetrials.html; http://www.gocorn.net/v2006/CornReports/2003cornreport/2003performancetrials.htm.

FIGURE A1 – CITATION COUNTS FOR PATENT-HYBRID PAIRS WITH 0 TO 34 CITATIONS, EXCLUDING 5 HIGHLY-CITED PATENTS THAT RECEIVE BETWEEN 136 AND 390 CITATIONS



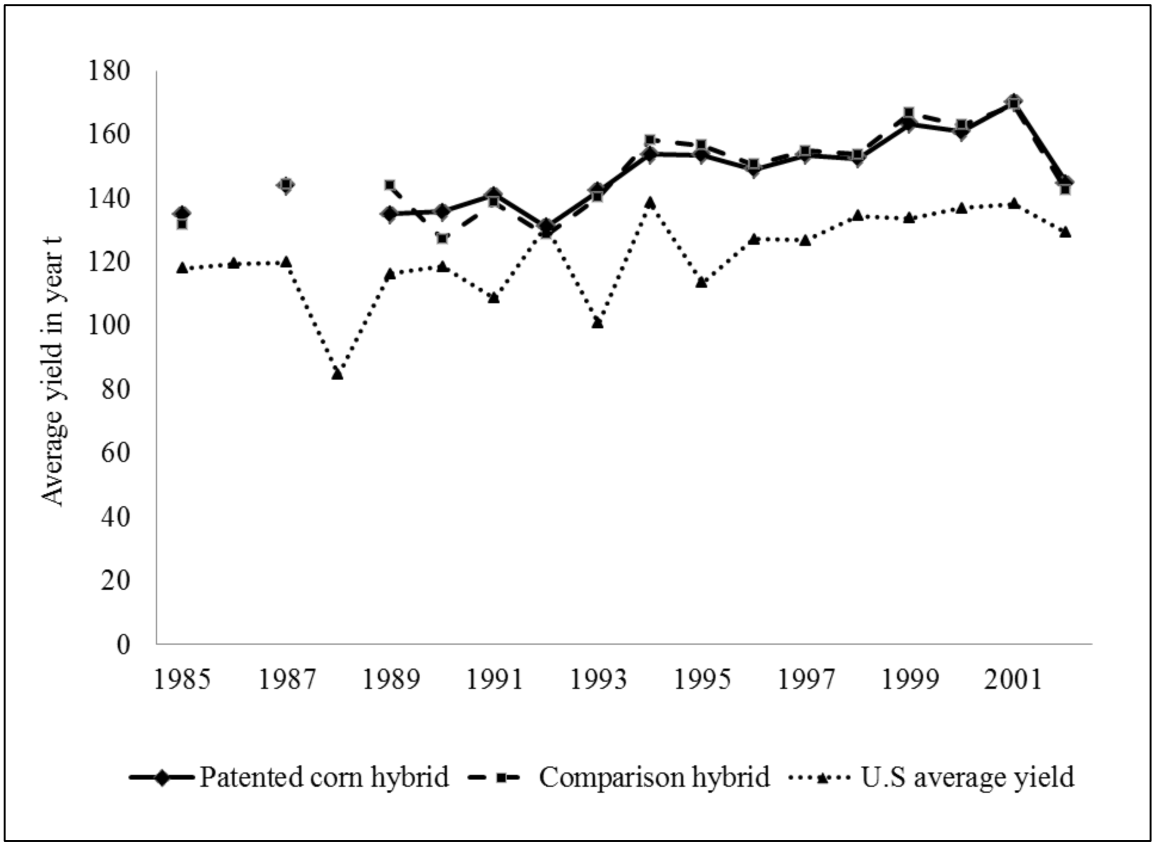

*Notes:* Citation counts for 310 patent – hybrid pairs for 264 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* (available at www.uspto.gov). Excluding patents US4,607,453 (136 citations), US4,629,819 (137 citations), US4,731,499 (693 citations), US4,737,596 (139 citations), and US6,433,261 (390 citations).

FIGURE A2 – CITATIONS PER YEAR FOR PATENT-HYBRID PAIRS



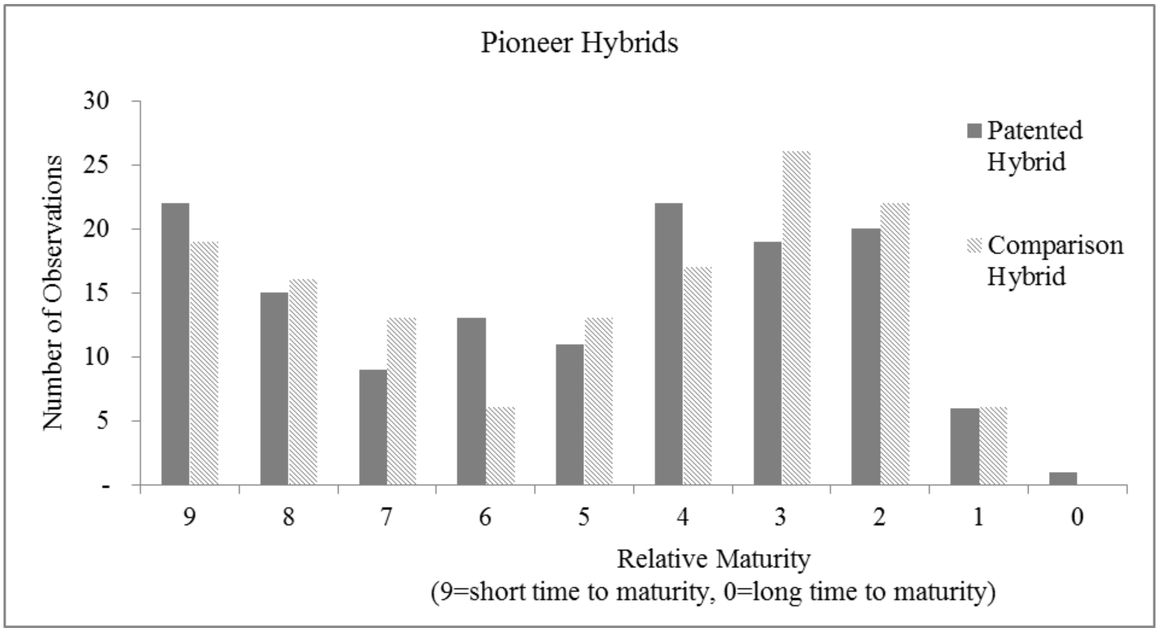

*Notes:* Citation counts per year for 315 patents – hybrid corn pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 Maize (available at www.uspto.gov). *Other patents* counts the sum of citations per year to 310 patent-hybrid pairs that received fewer than 100 citations. Among 5 patents with more than 100 citations, US4,607,453 received a total of 136 citations, USPTO 4,629,819 received a total of 137 citations, US4,731,499 received a total of 693 citations, US4,737,596 received a total of 139 citations and US6,433,261 received a total of 390 citations.

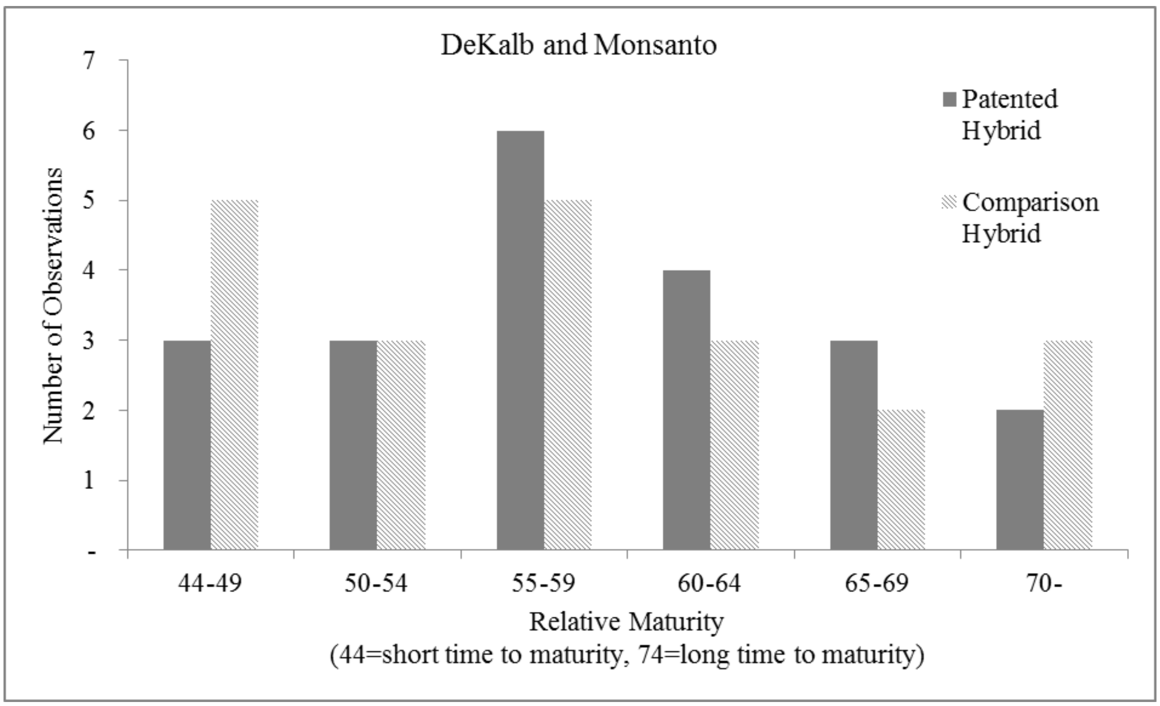
FIGURE A3 – AVERAGE YIELD PER YEAR, NEWLY PATENTED CORN HYBRIDS VERSUS COMPARISON HYBRIDS VERSUS U.S. AVERAGE YIELDS




*Notes:* Average yields per year of application for 269 patents issued 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).

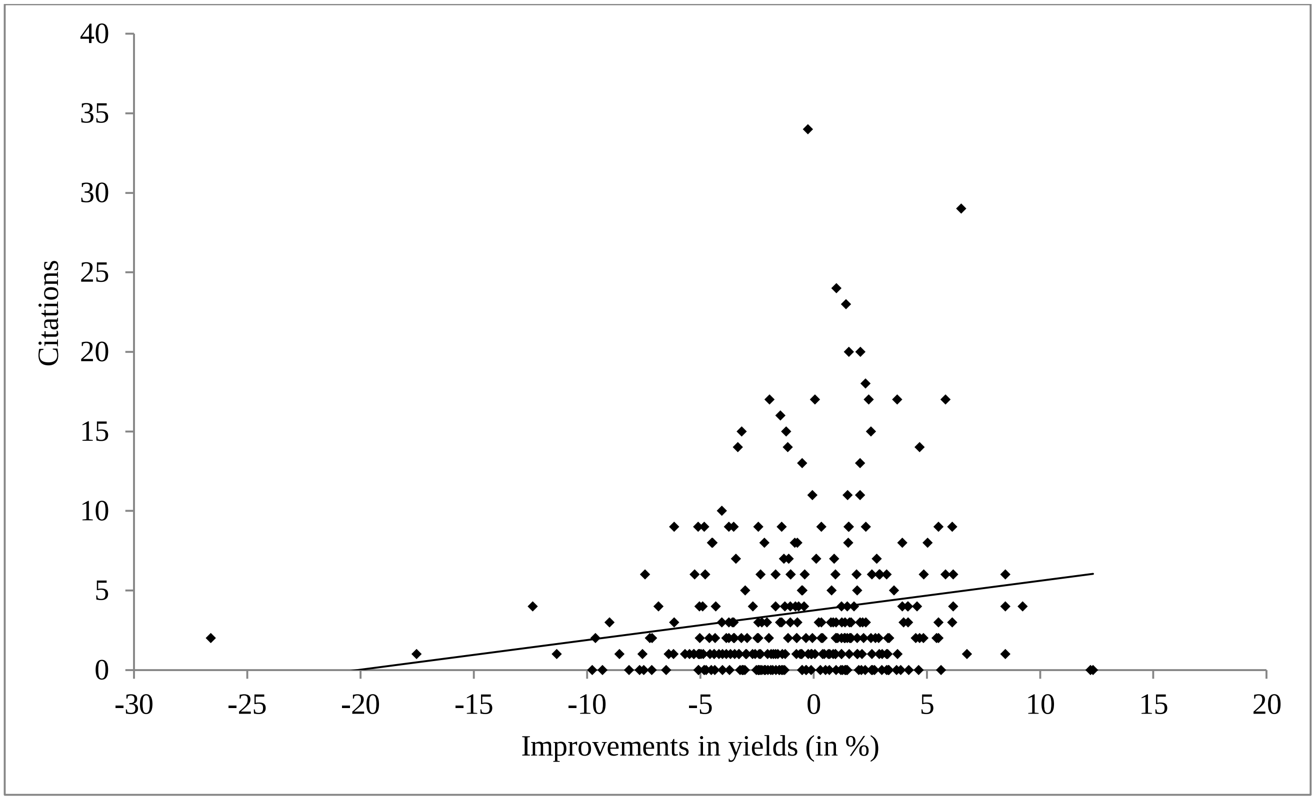
FIGURE A4 – DISTRIBUTION OF RELATIVE MATURITY
FOR NEWLY PATENTED AND COMPARISON HYBRIDS



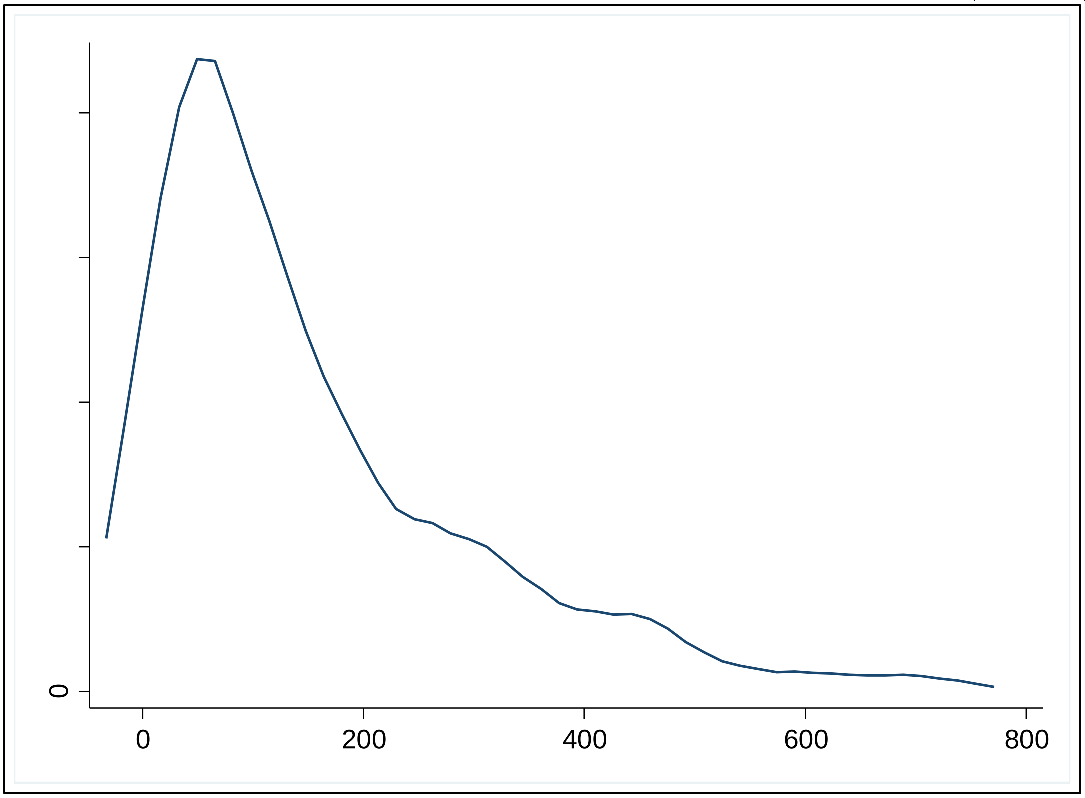

*Notes*: Information on relative maturity is encoded in the product name of new hybrids. The second digit of Pioneer's hybrid name identifies its relative maturity on a scale from 0 (very full) to 9 (very short).
See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming practices. For DeKalb and Monsanto, the first two digits of a hybrid's name identify its relative maturity; observed values of relative maturity range from 44 (short) to 74 (long).

FIGURE A5 – CITATIONS AND IMPROVEMENTS IN YIELDS FOR PATENT-HYBRID PAIRS WITH 0 TO 34 CITATIONS, EXCLUDING 5 HIGHLY-CITED PATENTS THAT RECEIVE BETWEEN 136 AND 390 CITATIONS




*Notes:* Improvements in corn yields and citations for 310 patent – hybrid pairs for 264 U.S. utility patents (excluding highly-cited patents) issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 Maize. Excluding patents US4,607,453 (136 citations), US4,629,819 (137 citations), US4,731,499 (693 citations), US4,737,596 (139 citations), and US6,433,261 (390 citations). Improvements in corn yields are calculated by comparing the yield of the new hybrid with the highest yield of comparison hybrids. The line fits a linear regression without controls, with an estimated intercept of 3.745, and a slope of 0.186 (with a standard deviation of 0.066).

FIGURE A6 – CITATION COUNTS FOR THE FIRST 500 PATENTS IN SUBCLASS 705/35 (FINANCE)




*Notes:* Citation counts for the first 500 US utility patents in subclass 705/35 *Finance* issued between October 25, 1977 and November 30, 2004 (available at www.uspto.gov).