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ABSTRACT

Patents are the main source of data on innovation, but there are persistent concerns that patents may be a noisy and biased measure. An important challenge arises from unobservable variation in the size of the inventive step that is covered by a patent. The count of later patents that cite a patent as relevant prior art – so called forward citations – have become the standard measure to control for such variation. Citations may, however, also be a noisy and biased measure for the size of the inventive step. To address this issue, this paper examines field trial data for patented improvements in hybrid corn. Field trials report objective measures for improvements in hybrid corn, which we use to quantify the size of the inventive step. These data show a robust correlation between citations and improvements in yields, as the bottom line measure for improvements in hybrid corn. This correlation is robust to alternative measures for improvements in hybrid corn, and a broad range of other tests.We also investigate the process, by which patents generate citations. This analysis reveals that hybrids that serve as an input for genetically-related follow-on inventions are more likely to receive self-citations (by the same firm), which suggests that self-citations are a good predictor for follow-on invention.

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1. INTRODUCTION

Patents have become the standard measure for innovation across a broad range of disciplines, fuelled in part by the availability of US patents after 1976 in the NBER data set on U.S. patents (Hall, Jaffe, and Trajtenberg 2001).[1] There are, however, widespread and persistent concerns about the usefulness of patents as a measure of innovation because "inventions that are patented differ greatly in 'quality,' in the magnitude of inventive output associated with them" (Griliches 1990, p. 1669).[2] Under the rules of the USPTO, applicants for patents are required to cite relevant patents as "prior art." These citations, which are systematically checked by patent examiners, have become a popular control for variation in the quality or size of the inventive step.[3]

To establish that citations are a good proxy for the quality of inventions, previous studies have compared counts of citations to more valuable patents with counts of citations to less valuable patents, using alternative measures for the value of patented inventions. For example, Carpenter, Narin and Woolf (1981) show that patents for 100 products that the journal *Industrial and Research Development* had identified as particularly important technical contributions in 1969 and 1970, were cited 2.4 times as often as control patents that had been issued in the same year were.[4] An important strand of this literature has established that citations are correlated with the *private* value of patents, measured through variation in

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[1] For example, Schmookler 1962, 1966; Sokoloff 1988; Aghion et al. 2005; Cockburn and MacGarvie 2011; Bloom, Schankerman, and VanReenen forthcoming. More recently, a collaboration between the United States Patent and Trademark Office (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; Bloom, Schankerman, and VanReenen forthcoming, and Moser, Voena, and Waldinger 2012. Lampe and Moser 2013 construct historical data on citations, starting in 1921.

[2] Also see Kuznets (1962, p. 37): "the main difficulty with patent statistics is, of course, the enormous range in the magnitude of the inventions covered."

[3] E.g., Kortum and Lerner 2000; Sørensen and Stuart 2000; 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). Prize data, however, cannot quantify the size of the inventive step beyond the level of crude distinctions in gold, silver, and bronze awards, and are not available for most 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 as well as the large majority of commercial R&D.

[4] 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.

the stock market value of U.S. firms (Hall, Jaffe, and Trajtenberg 2005; Kogan et al. 2012), with the valuations that R&D managers report for patents (e.g., Harhoff, Narin, Scherer, and Vopel 1999), and with the licensing revenue that non-practicing entities (aka patent trolls) can extract from a patent (Abrams, Akcigit, and Popadek 2013). Moreover, Trajtenberg (1990) has shown that citation counts are correlated with the *social* value of patented invention, proxied by the estimated social surplus of 456 improvements in CT scanners.

Recent empirical research, however, indicates that citations may be a biased measure for the quality of patented inventions because applicants withhold citations strategically, for example, to minimize license fees and litigation risks (Sampat 2010; Lampe 2012). Sixty-three percent of all citations in patents issued between January 2001 and August 2003 were added by examiners (Alcácer and Gittelman 2007, p. 775). Examiner-added citations may be a noisy measure for the quality of inventions if examiners cite a small set of "favorite" patents or miss citations when they are less familiar with the subject matter (Cockburn, Kortum, and Stern 2002). For example, examiners and patentees may be more likely to miss relevant citations in areas that have only recently become patentable, such as financial methods (Lerner 2002) or biotechnology, leading citation counts to misstate the quality of patented inventions. These issues are particularly severe in periods when the workload of examiners is high (Merrill et al. 2004, p. 51; Lemley 2001).[5]

To investigate whether citations are a good proxy for the size of the inventive step, we link patents for hybrid corn with performance data on improvements in yields, as an objectively quantifiable bottom-line measure for the size of the inventive step.[6] Hybrid corn, which is one of the most important crops today, has also played a critical role in the history of plant breeding and economic analyses of

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[5] In a data set of 182 U.S. patents, for which the Court of Appeals for the Federal Circuit (CAFC) ruled on validity between 1997 and 2000, missing citations were the most common cause for invalidation (Cockburn, Kortum, and Stern 2002). More generally, Lemley and Sampat (2012) find that more experienced examiners, and those who cite fewer previous patents, are more likely to grant applications.

[6] The size of the inventive step is most closely related to the technological importance of an innovation, which is distinct from its private or social value. 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 a market equilibrium."

innovation. U.S. breeders began to create hybrids by crossing two inbred corn plants after 1908, when plant scientists George H. Shull and Edward M. East discovered that the experimental cross between two inbred plants produced more corn than plants that had been allowed to pollinate in the field. In 1923, Henry A. Wallace, founder of the Pioneer Seed Company, began to commercialize *Copper Cross*, the first hybrid to win a gold medal at the prominent Iowa Corn Yield Contests.[7] Improvements in yields helped fuel a rapid shift from open-pollinated corn to hybrid corn between 1933 and 1960. In 1933, hybrid seed was planted on less than 1 percent of U.S. corn acreage. By 1939, its share had risen to almost half. By 1960, nearly all U.S. corn acreage was hybrid seed (Griliches 1957, 1960; Olmstead and Rhode 2008).[8] In 1996, the entry of the US chemical firm Monsanto into plant breeding business, and the introduction of genetically-modified (GM) crops marked another important transition for the industry.

In 1985, an improvement in hybrid corn had become the first sexually-propagated plant to be subject to a utility patent, when the 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).[9] To establish patentability, seed companies began to report field trial comparisons for new hybrids with existing hybrids, starting with the first patent application. Seed companies reported these data consistently until 2002.[10] A total of 269 U.S. patents for hybrid corn granted between 1986 and 2005, covering 277 corn hybrids, include detailed performance data from field trials. We use this information to create a rich new data set that includes counts of citations, improvements in yields, moisture, and other

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

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

[9] 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.

[10] In 2002, a major seed company, Pioneer Hi-Bred, stopped reporting data on the percent moisture (water) in corn at harvest, which allows farmers to calculate expected profits from a seed. See the data section for additional detail.

characteristics for 315 patent-hybrid pairs.[11]

Confirming concerns about raw patent counts, data for corn hybrids indicate that raw patent counts are a poor measure for the size of the inventive step. Most newly patented corn hybrids produce *less* corn than existing hybrids. On average, a patented corn hybrid yields 0.8 percent *less* corn than existing hybrids, with a standard deviation of 4.8. Interviews with patent officers confirm that plants do not need to be improvements over existing plants to be patentable (e.g., Benzion 2009).[12] The data, however, also indicate that patent citations are robustly correlated with the size of the inventive step in hybrid corn. Poisson estimates indicate that a 1 percent increase in yields for a patented hybrid is associated with 0.7 to 0.8 additional citations.

Attorneys appear to cite a small group of highly cited patents mostly to establish the patentability of corn hybrids. Five patents are cited as relevant prior art in 693, 390, 139, 137, and 136 patents, respectively. These patents yield 1.5 percent more corn than the comparison hybrid, which confirms the positive correlation between citations and the size of the inventive step. Side-by-side comparisons of patent documents, however, reveal that patent attorneys copy portions of these early patents in their applications, and appear to cite them mainly to establish the patentability of corn hybrids.

In addition to examining the correlation between citations and patent quality, our new data on field trials and patents makes it possible to document several important characteristics of the market for genetically modified crops. We examine how firms and their attorneys write patents, how patent examiners review patents, and how economists' measures of patent values may be influenced by these facts. Data on examiner-added citation confirm that examiners play a crucial role in determining the pool of cited patents. The citation that is most likely to have been added by an examiner (rather than the

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[11] Some hybrids are covered in more than one patent; some patents cover more than one hybrid. In our empirical analysis, we add controls to address issues arising from this multiplicity.

[12] If patent examiners, however, only require new hybrids to be "different," rather than "better," the incentive to choose comparison hybrids strategically may be low. It is also telling that the majority of patented hybrids do not show any improvement in yields. In addition to interviewing Examiner Gary Benzion, we also communicated on the record with Examiner Anne Marie Grünberg in October 2009 and off the record with four officials at U.S. and international patent offices between October 2009 and October 2013.

applicant) is the citation to the most recently issued patent. 135 of 421 examiner-added citations are linked with the most recently issued patent in the list of references. Examiners also appear to be more likely to add early, foundational patents, which are listed first in the reference list; 20 examiner-added citations are the very first cited patent in the list of references. After examiners introduce these patents to the "pool" of cited patents, breeders' patent attorneys follow their lead and include the cited patents in their own list of relevant citations.

We also find that self-citations – when a firm cites its own patent as relevant prior art – can be a useful predictor for the rate and direction of cumulative innovation. 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…" On the other hand, firms may cite their own patents strategically, so that self-citations are a poor indicator for patent quality. We link patented hybrids in our sample with genetically similar (follow-on) hybrids by the same breeder to examine whether self-citations are a useful proxy for follow-on or cumulative innovation. Consistent with the arguments of Hall et al (2005), we find that self-citations are a good predictor for follow-on invention.

2. DATA

2.1. Utility patents for hybrid corn

Between August 26, 1986 and March 8, 2005, the USPTO issued 269 patents for hybrid field corn in subclass *800/320.1 Maize*; these patents have application dates between February 21, 1985 and September 9, 2002.[13] Data on patents per year show that seed companies initially only applied for a small number of patents. For example, DeKalb Genetics applied for two patents immediately after the *Hibberd* ruling in 1985 (US4,607,454 and 4,629,819) but waited until 1990 to apply for another patent

[13] 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.

(US5,589,605 for hybrid *EXP 748*, issued December 31, 1996). After 1993, patents began to increase, reaching 13 patents in 1994, 58 in 1999 and 31 in 2001.

Side-by-side comparisons of patent documents indicate that seed companies' attorneys use patents that have already been approved by examiners as templates for additional applications, so that patents by the same seed company typically look very similar to onbe another. For example, Pioneer's patent US5,574,209 for hybrid seed *3951* (filed March 8, 1995, issued November 12, 1996) is nearly indistinguishable from Pioneer's patent US5,929,311for hybrid seed *32J55* (filed January 31, 1997, issued July 27, 1999).

Each of Pioneer's 142 patents covers only a single hybrid, but 18 patents by other firms cover more than one hybrid. For example, DeKalb's US6,072,108, cover two hybrids. Fifteen of the 18 patents that cover more than one hybrid are assigned to DeKalb, 2 are assigned to Monsanto and 1 is assigned to Euralis. On average, the 269 patents in our sample cover 1.2 hybrids, with a standard deviation of 1.1, a minimum of 1, a median of 1, and a maximum of 10. DeKalb's 110 patents cover 1.4 hybrids with a standard deviation of 1.2, and a median of 1, and a maximum of 10.

Forty of 277 patented corn hybrids (14 percent) are covered by two or more patents; 28 hybrids are covered by 2 patents, 12 hybrids are covered by 3 patents; 35 of these patents are assigned to DeKalb, 3 to Rustica Prograin Genetique and 2 to Pioneer. 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.

2.2. Field trial data on yields and moisture

269 successful patent applications between 1985 and 2002 cover 277 corn hybrids that target the North American market (315 patent-hybrid pairs, Table 1). To demonstrate the novelty of patented hybrids, seed companies begin to report data on the field trial performance of new corn hybrids from the first patent application on February 25, 1985 until September 9, 2002. These reports, which continue a scientific practice in agronomy and crop sciences (Troyer 1990), include yield data for new and existing

hybrids under comparable growing conditions.[14] Although patent examiners do not inspect the trials, they require applicants to certify that the information is "true and correct," and misreporting would invalidate the patent (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, as the bottom line "trait of major commercial interest" (US5,449,855, issued September 12, 1995, p. 4), serve as a summary statistic for improvements across a broad range of traits, including adaptability to adverse soil and weather conditions, as well as resistance to diseases and pests. Yields are reported as bushels of shelled corn harvested per acre planted, normalized to a moisture level of 15.5 percent in all applications.[15]

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 calculate the size of the inventive step as the yield difference between the patented hybrid and best comparison hybrid. For example, DeKalb applied to patent the "Novel Hybrid Corn Plant" *dk524* on April 26, 1985 (issued December 16, 1986, as US4,629,819). Hybrid *dk524* yields 136.5 bushels per acre, and is compared with two existing hybrids: DeKalb's *T1000*, and Pioneer's hybrid *3732*. Among the comparison group, hybrid *3732* produces most corn, with 128.0 bushels per acre, which implies that the patented hybrid *dk524* produced (136.5-128.0)/128.0 or 6.6 percent more corn than the best comparison hybrid. We calculate these improvements for 315 patent-hybrid pairs in our sample; the distribution is bell-shaped, with a peak at a 1.0 percent improvement in yields (Figure 1).[16]

Field trial data also include information on moisture, as a proxy for the costs of making corn marketable. For example, the Agricultural Extension Service of Purdue University explains in its "Grain Quality Fact Sheet"

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[14] Patent applications by Pioneer after September 9, 2002, no longer include information on the moisture content of plants.

[15] A bushel weighs 56 lbs. or 25.4 kg.

[16] Excluding the 5 highly cited patents from the sample produces no perceptible change in the distribution of yields.

> 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).…The extra expense will be in the form of increased fuel costs and drying time (less drying capacity) (Uhrig and Maier 1992).

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*).

2.3. Patent citations

To collect data on forward citations, we search *the USPTO Patent Full-Text Database (PatFT)* for patents that cite the 269 hybrid corn patents as relevant prior art.[17] This search captures forward citations until October 23, 2012, which allows us to observe citations to each hybrid corn patent for a minimum of 7 years.[18]

The distribution of citations for hybrid corn patents closely resembles the distribution of citations in the NBER data set, albeit with a larger share of highly-cited patents (Appendix Figure A1). Among 269 patents for hybrid corn, 203 are cited at least once, and the average patent is cited 9.1 times between 1985 and 2012. Counting each of the 315 patent-hybrid pairs as a separate observation, 245 pairs are cited at least once, and the average pair is cited 8.3 times.[19] By comparison, 2,240,448 of 2,923,922 patents in the NBER data set are cited at least once, and the average patent in the NBER patent data is cited 3.0 times within 5 years, 5.3 times within 10 years, and 7.3 times within 25 years (Hall, Jaffe, and Trajtenberg 2001).[20] In the NBER data set, 322 patents (0.01 percent of all patents) receive at least 136 citations.

Our data also indicate a rapid increase in citations after 1997, when patenting for hybrid corn

[17] Available at http://patft.uspto.gov.
[18] The most recent patent in our data, US6,864,409 was filed on September 9, 2002 and issued on March 8, 2005.
[19] Excluding the 5 highly cited patents, the average corn patent is cited 3.6 times within 17 years. Counting each of the 310 patent-hybrid pairs as a separate observation, the average pair receives 3.6 citations (Table 1).
[20] For patents issued between January 1, 1963 and December 31, 1999 and citing patents issued between January 1, 1975 and December 31, 1999, from Bronwyn Hall at http://elsa.berkeley.edu/~bhhall/patents.html, accessed in January 2013.

increased.[21] This increase in patenting appears to have been driven by the entry of U.S. chemical firms Monsanto and DuPont into the plant breeding industry, as part of "an intense race by the globe's chemical giants to build businesses that can exploit their expanding knowledge about genetic engineering of plants" (Kilman 1998).

2.4. Examiner-added citations

To examine the influence of examiners on the quality of citations (e.g., Alcácer and Gittelman 2006; Lampe 2010; Sampat 2010; Lemley and Sampat 2012), we compare citations that were added by examiners with citations that were included by the patent attorney who drafts the application on behalf of a patentee.[22] The USPTO's records make it possible to distinguish examiner-added citations for patents issued after December 31, 2000).

3. RESULTS

Among 315 patent-hybrid pairs, less than half (142 pairs, or 45 percent) produced more corn than the highest-yielding existing hybrid in the same trial. On average, patented hybrids produced 0.8 percent less corn than the highest-yielding comparison hybrids, with a standard deviation of 4.9 percent (Table 1, Panel A). The median hybrid, US6,028,248 for Pioneer's *36h75*, produced 0.5 percent less than the comparison hybrid.[23]

Comparisons over time also indicate that improvements in yields declined with the sharp rise in patent applications in the 1990s. For most years between 1985 and 1992, the average yield of newly

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[21] 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.
[22] Using *Google Patents* (available at www.google.com/patents, accessed in February 2013).
[23] At the extreme ends of the distribution, US6,646,188 for *psa104_sg* produced 12.3 percent more, and US6,362,403 for *dk591* produced 36.6 percent less corn than the highest-yielding comparison hybrid.

patented hybrids exceeded the average yield of the highest-yielding 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, newly patented hybrids begin to consistently yield *less* corn compared with the highest-yielding existing hybrids, with 153.7 versus 158.2 in 1994, and 160.9 versus 162.9 in 2000.[24]

Estimates for the size of the inventive step are roughly comparable across nine primary patent examiners who issued 269 patents for corn hybrids between August 26, 1986 and March 8, 2005, which suggests that variation in granting behavior across examiners cannot fully explain the observed variation in patent quality.[25] Interviews with patent examiners confirm the potential for variation in the size of the inventive step. For example, Examiner Benzion (2009) explained that, to be issued a utility patent, plants must only be different, but not better than existing plants.

3.1. Patent citations and yields

Data on improvements in yields, however, also indicate a positive correlation between citations and the size of the inventive step (Appendix Figure A5 and A6). To investigate the correlation between citations and the size of the inventive step more systematically we estimate

$$citations_i = \beta_0 + \beta_1\, yields_i + \beta_2\, moisture_i + \delta_t$$

where the outcome variable *citations* measures the count of patents that cite patent *i*. Baseline estimates are calculated as average marginal effects of the quasi-maximum-likelihood (QML) Poisson to address the count data characteristics of citations; 22.2 percent of hybrid patent pairs receive zero citations. We also estimate OLS as a robustness check.[26] The explanatory variable *yields* measures the percent increase

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[24] Changes in reported yields track improvements in yields for patented corn hybrids over time. 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). Yields are also less variable in field trials compared with the US average (with a standard deviation of 144 compared with 201 for U.S. average yields), which is most likely due to controlled growing conditions in field trials.
[25] The top two examiners issued 201 and 34 patents, respectively.
[26] 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

in yields for the hybrid in the patent-hybrid pair *i*, calculated as the difference between the yield of the patented hybrid and the yields of the highest-yielding existing hybrid in the same trial, divided by the yield of the highest-yielding existing hybrid. The variable (relative) *moisture* measures the water content of a corn hybrid at harvest relative to the water content of the highest-yielding comparison hybrid. Fixed effects δ_t for the application years of cited patents control for a potential increase in citations for any patent over time, independent of the quality of patents. For example, patent citations to all patents may increase as a result of an increase in patenting (e.g., Kortum and Lerner 1999), or with a shift towards computerized search which makes it easier to identify relevant prior art.[27]

Baseline estimates confirm the positive link between citations and the magnitude of improvements. A 1 percent increase in yields for a patented hybrid is associated with 0.8 additional citations (Table 2, column 5, significant at 1 percent). Consistent with the view that yields are the most useful summary statistic for improvements in new hybrids (for example, Griliches 1957, 1960; Olmstead and Rhode 2008), estimates for *moisture* are not statistically significant and small (with an estimate of -0.1 and a p-value of 0.631, Table 2, column 5). The positive association between improvements in yields and citations is also robust to excluding *moisture*; a 1 percent increase in yields is associated with 0.7 additional citations (Table 2, column 4, significant at 1 percent). Regressions with additional controls for hybrids covered by *>1 patent* and for patents that cover *>1 hybrid* indicate that a 1 percent increase in *yields* is associated with 0.8 additional citations (Table 2, column 6, significant at 5 percent).

OLS estimates of the baseline specification indicate that a 1 percent increase in yields for a patented hybrid is associated with 0.5 additional citations (Table 2, column 2, significant at 5 percent), which is 35 percent smaller compared than the average marginal effect of 0.8 in the QML Poisson.

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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). We use the STATA13 command *gml (poisson)* to estimate this model.

[27] 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. Poisson specifications with grant year fixed effects confirm the results of the main specification; baseline estimates imply that a 1 percent increase in yields is associated 0.891 with additional citations (significant at 1 percent). 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.

Coefficients for *moisture* are again not significant (Table 2, column 2, p-value 0.912), and results are robust to excluding *moisture* (with an estimate for *yields* of 0.5; Table 2, column 1, significant at 5 percent). Estimates are also robust to including controls for *>1 patent* and for *>1 hybrid* (with an estimate for *yields* of 0.5; Table 2, column 3, significant at 5 percent).

3.2. Highly cited patents (>100 citations)

Five patents receive more than 100 citations. On average, these patents yield 1.5 percent *more* corn than the best (highest-yielding) comparison hybrid, compared with 0.8 percent *less* corn for the average patented hybrid. The most recent highly cited patent, DeKalb's patent US6,433,261 (issued August 13, 2002) had been cited as relevant prior art in 390 patents. In field trials, the hybrid plant 8012685 that it covers yields 2.6 percent more corn than the comparison hybrid, consistent with the positive link between citations and the size of the inventive step.[28]

The most highly cited patent, however, Pioneer's US4,731,499, is among the first patents for hybrid corn, and may have been cited mainly to document that hybrid corn can be patented. By May 2010, US4,731,499 for a "Hybrid corn plant and seed" (filed January 29, 1987, issued March 15, 1988) had been cited 693 times; it covers hybrid *3790*, which yields 2.8 percent more corn than the comparison hybrid (Table 3).

The *Background* section of US4,731,499 includes a description of the process of breeding hybrid corn; this description is copied verbatim by nearly all citing patents. One of the citing patents is another early Pioneer patent, US4,737,596 (filed January 29, 1987, issued April 12, 1988), which itself has 139 citations. 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

[28] US6,433,261 covers the inbred corn plant 89AHD12, as well as the process of hybridization, which creates hybrid 8012685: "The present invention also provides corn seed and plants produced by a process that comprises crossing a first parent corn plant with a second parent corn plant, wherein at least one of the first or second parent corn plants is the inbred corn plant designated 89AHD12…An example of such a hybrid which can be produced with the inbred designated 89AHD12 is the hybrid corn plant designated 8012685."

fast dry-down in the field" but yields 2.9 percent *less* corn than existing plants.

Pioneer's two highly cited patents are typically cited together, possibly to establish the patentability of improvements in hybrid corn. Any patent that cites the lower-yielding US4,737,596 also cites US4,731,499, and until 2001, nearly all citations to the two patents cite both. Citations to US4,731,499 peak in 2008, with 166 citations for US4,731,499 (Appendix Figure A2).

Two highly cited DeKalb patents were the first patents issued after *Ex parte Hibberd*; these patents are cited by nearly all of the company's later patents. DeKalb's patent US4,629,819 (filed April 26, 1985, issued December 16, 1986) is cited 137 times; its hybrid *dk524* yields 6.6 percent more corn than the highest-yielding comparison hybrid. DeKalb's patent US4,607,453 (filed February 21, 1985, issued August 26, 1986) is cited 136 times, and its hybrid *dk672* yields 1.7 percent *less* corn than the highest-yielding comparison hybrid.

Citations to both of DeKalb's highly cited patents and one of Pioneer's highly cited patent (U.S. 4,737,596) are nearly identical because attorneys and examiners typically cite these three patents as a group. For example, 22 patents cite the 3 patents as a group in 1997, and 17 patents cite them as a group in 2002 (Appendix Figure A2).

3.3. Excluding highly cited patents

If highly cited patents are cited mainly to establish patentability, including them in counts of citations may reduce the usefulness of citations as an indicator for the size of the inventive step. To investigate this issue, we repeat the main specifications excluding data for highly cited patents, which reduces the sample to 310 patent-hybrid pairs (Table 1, Panel B). Estimates with this restricted sample indicate that a 1 percent increase in yields for a patented hybrid is associated with 0.2 additional citations (Table 4, column 5, significant at 1 percent), compared with 0.8 additional citations in the full sample. Estimates for *moisture* are statistically insignificant.

The correlation between improvements in yields and citations is robust to excluding *moisture*; a 1 percent increase in yields is associated with 0.2 additional citations (Table 4, column 4, significant at 1 percent), compared with 0.7 additional citations in the full sample. Regressions with additional controls for *hybrids covered by >1 patent* and for *patents that cover >1 hybrid* indicate that a 1 percent increase in *yields* is associated with 0.2 additional citations (Table 4, column 6, significant at 1 percent).

OLS results are qualitatively similar to estimates from the QML Poisson. OLS estimates of the baseline indicate that a 1 percent increase in yields is associated with 0.2 additional citations (Table 4, column 2, significant at 1 percent), compared with 0.2 for Poisson (Table 4, column 5). As above, coefficients for *moisture* are not significant (Table 4, column 2, p-value 0.653), and estimates are robust to excluding *moisture* (with an estimate for *yields* of 0.2, Table 4, column 1, significant at 1 percent), as well as including controls for hybrids covered by *>1 patent* and for patents that cover *>1 hybrid* (with an estimate for *yields* of 0.1; Table 4, column 3, significant at 1 percent).

3.4. Examiner-added citations

To examine the influence of examiners on the quality of citations, we measure the share and the type of citations that have been added by examiners, rather than patentees. As described in the data section, data on examiner-added citations are available for patents issued after 2000. These data indicate that the share of examiner-added citations is roughly comparable to shares in other industries: 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).[29]

The data also suggest that examiners play an important role in identifying patents as relevant prior art, and that patentees incorporate examiner-added citations to their pool of cited patents for subsequent applications. Among 198 patents that are cited as relevant prior art in patents issued after 2000, 128 patents (64.7 percent) were first cited by an examiner. By comparison, 70 patents were first cited by an

[29] For citing patents issued until August 2003. Extending the data to include patents with 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.

inventor. For example, an examiner added DeKalb's patent US6,433,261 for "Inbred corn plant 89AHD12 and seeds thereof" (by Jay R. Hotchkiss filed Jan 8, 2001, issued Aug 13, 2002) as relevant prior art to three patents issued in 2006 and 2007 (US6,989,478, US7,173,171, and US7,186,906). After the examiner cites this patent, patentees add 384 in 390 total citations to the patent.

Comparing shares of examiner-added citations across cohorts of citing patents confirms that examiner-added citations are more frequent in early cohorts. Algorithm-collected USPTO data on examiner-added citations include 22 hybrid corn patents with issue dates between January 2001 and August 2003. In cohorts of citing patents until August 2003, these patents receive 71 citations, including 28 examiner-added citations, which implies a 39.44 percent share of examiner-added citations. By comparison, hand-collected data include 23 hybrid corn patents with issue dates between January 2001 and August 2003.[30] 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 of examiner-added citations.

Data on the age of patents that examiners add to the list of cited patents indicate 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 also confirm that examiners may be more likely to cite a small group of favorite examples of prior art that 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 citations to 385 prior patents; among these 385 patents, the median patent is cited once by an examiner, and the average patent

[30] To match data in Alcácer and Gittelman (2006); citations from www.google.com/patents, accessed in February 2013.

is cited 1.1 times with a standard deviation of 0.3. One patent US5,859,355, for the "Inbred corn plant 17DHD12 and seeds thereof" is added 29 times by the same examiner, suggesting that it may have been one of the examiners "favorite" patents. The same patent is added once by another examiner, and only 4 times by a patentee.

Re-estimating the baseline specification with examiner-added citations as the dependent variable, indicate that a 1 percent increase in yields is associated with 0.1 additional examiner-added citations (Table 5, column 5, significant at 10 percent). Estimates for the effects of *moisture* on examiner-added citations are not significant (Table 5, column 5, p-value 0.722). Estimates are robust to excluding *moisture* (with an estimate for *yields* of 0.1, Table 5, column 4, significant at 5 percent), as well as including controls for hybrids covered by >*1 patent* and for patents that cover >*1 hybrid* (with an estimate for *yields* of 0.1; Table 5, column 6, significant at 10 percent). 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 0.2 additional citations (Table 5, column 2, significant at 1 percent), more than double the estimate for examiner-added citations. Estimates for the effects of *moisture* on examiner-added citations are not significant (Table 5, column 2, p-value 0.488). Estimates are robust to excluding *moisture* (with an estimate for *yields* of 0.2, Table 5, column 1, significant at 1 percent), as well as including controls for hybrids covered by >*1 patent* and for patents that cover >*1 hybrid* (with an estimate for *yields* of 0.2; Table 5, column 3, significant at 1 percent).

3.5. Other improvements in hybrids: Insect resistance and herbicide tolerance

In addition to detailed information on yields and moisture, which is available for all 277 hybrids, information on insect resistance and herbicide tolerance, are available for a subset of the hybrids in our data. Insect resistant corn was first introduced in 1996. It contains a gene from the soil bacterium *bacillus thuringiensis* (Bt), which produces a protein that is toxic to the European corn borer, and other insects that threaten corn (Fernandez-Cornejo and Wechsler 2012). Herbicide tolerant corn was introduced in the same year; it is able to survive the application of glyphosate and other powerful herbicides, which allow farmers to control weeds with substantially lower labor costs (Fernandez-Cornejo et al. 2014).[31] By 2013, Bt corn accounted for 76 percent of US corn acreages, and herbicide tolerant corn accounted for 85 percent (USDA-ERS 2013). Drought tolerance is a more recent genetically modified trait and was approved for commercial use only in 2011 (Fernandez-Cornejo et al. 2014).

For 165 hybrids in our sample, we can collect information on improvements in insect resistance and herbicide tolerance by linking product codes that are given in the patent document with information on these characteristics in product catalogues, press releases, and independent field trials.[32] These data indicate that most hybrids in our sample are neither insect resistant nor herbicide tolerant. Only 1 hybrid is both insect resistant and herbicide tolerant; 11 are insect resistant only and 3 are herbicide tolerant only.

3.6. Other characteristics in hybrids: Relative maturity

New hybrids are developed to take advantage of differences in climatic conditions across the United States and Canada. Locations with colder climates and shorter summers are better suited for hybrids that require fewer days to grow relative to the full growing season; breeders and farmers refer to proxies that measure this variation as "relative maturity".

To measure differences in relative maturity we exploit the fact that the mayor seed companies in our sample – Pioneer, DeKalb and Monsanto – encode relative maturity in the product name of their 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).[33] For example, the digit 9 in the 39r34 (USPTO 6,797,868 granted on September 28, 2004) indicates that this hybrid has a very short relative maturity. Information on relative maturity is available for 138 of 141 Pioneer hybrids in our data. For DeKalb and Monsanto, the first two digits of a hybrid's name identify its relative maturity. Information on relative maturity is, however, only available

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[31] Herbicides introduced into the market include Roundup by Monsanto and LibertyLink by Bayer CropScience.
[32] 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 12 for a list of field trials.
[33] See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming practices.

for 21 of 120 DeKalb and Monsanto hybrids.[34] For these hybrids, observed values of relative maturity range from 44 (short) to 74 (long).

These data indicate that patented hybrids and the comparison hybrid target comparable locations.[35] 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 hybrid. 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 hybrid; 7 hybrids (33.3 percent) are a single category away from the comparison hybrid, 3 hybrids (14.3 percent) are 2 categories away and another 4 hybrids (19.0 percent) are 3 categories away. Only 1 hybrid (4.8 percent) is 4 categories away and none are more distant.

3.7. Cumulative invention: patented hybrids as "parents" to other hybrids

We also examine whether seed companies use patents as a means to protect improved (follow-on) versions of the same hybrid and use information on follow-on hybrids as a proxy for cumulative innovation (Scotchmer 1991). To perform this analysis we search seed catalogues, press releases, and field trial reports for genetically similar hybrids that breeders introduced within a five- year window of applying for one of the patents in our sample. For example Pioneer's 2006 product catalogue lists hybrid 39k40 (US6,809,242, issued October 26, 2004, not insect resistant) as a parent for the insect resistant hybrid 39k41, which first appears in Pioneer's catalogues in 2006 (Pioneer 2006, p.1). 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). For 150 hybrids in our data, information on follow-on hybrids is available for a

[34] For the remaining 99 hybrids, breeders report development rather than product codes.
[35] Appendix Figure A4 plots the distribution of hybrids across categories of relative maturity. 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.

minimum of 5 years.[36] For 57 hybrids (38 percent) we observe the introduction of a genetically related follow-on within 5 years after the same breeder has applied for a patent. Among 57 follow-on hybrids, 34 hybrids are both insect resistant and herbicide tolerant; 20 are only insect resistant and 3 are only herbicide tolerant.

Consistent with the idea that seed companies sometimes use patents to protect follow-on inventions, we find that the average increase in yields is slightly more negative for 57 patented hybrids with follow-on hybrid (-1.4 percent) compared with 93 patented hybrids without follow-on hybrids compared (-1.2 percent). Regressions with indicator variables for *insect resistant* and *herbicide tolerant* follow-on hybrids indicates that patent-hybrid pairs which serve as an input to at least one *insect resistant* follow-on hybrid receive 3.9 additional citations (Table 7, column 2, significant at 10 percent), while estimates for *herbicide tolerant* follow-on hybrids indicate 7.0 additional citations (Table 7, column 2, significant at 1 percent). Estimates for *yields* remain positive and statistically significant; indicating that a 1 percent increase in yields is associated with 1.0 additional citations (Table 7, column 2, significant at 10 percent). Estimates for the effects of *moisture* on citations are not significant (Table 7, column 2, p-value 0.984). Estimates for *yields* are robust to excluding the indicator variables for *insect resistant* and *herbicide tolerant* follow-on hybrids (1.1, Table 7, column 1, significant at 5 percent). Excluding patents with more than 100 citations reduces the size of the estimate for *insect resistant* follow-on hybrids to 1.4 additional citations (Table 7, column 4, significant at 5 percent), and for *herbicide tolerant* follow-on hybrids to 2.6 additional citations (Table 7, column 4, significant at 1 percent). Estimates for *yields* remain positive and statistically significant; indicating that a 1 percent increase in yields is associated with 0.1 additional citations (Table 7, column 4, significant at 5 percent). Estimates for the effects of *moisture* on citations are not significant (Table 7, column 4, p-value 0.160). Estimates for *yields* are robust to excluding controls for *insect resistant* and *herbicide tolerant* follow-on hybrids (0.1, Table 8,

[36] Fifteen additional hybrids were insect resistant or herbicide tolerant (section *3.5*). Data on follow-on hybrids by Pioneer are drawn from the Pioneer's "Corn Hybrid-Herbicide Management Guide" (2004, 2005 and 2006 edition) issued by Pioneer. For other hybrids, we collect data on follow-on hybrids from press releases and field trial reports. See the Table 12 for a list of field trials.

column 3, significant at 5 percent).

Estimates with examiner-added citations as the dependent variable suggest that follow-on GM hybrids do not lead to more examiner-added citations. Coefficients for *insect resistant* follow-on hybrid and *herbicide tolerant* follow-on hybrids are not significant (Table 8, column 4, p-value 0.739, and 0.713, respectively). Since examiner-added citations are only available for patents that were issued after 2000, we also estimate the baseline specification for all (examiner-added and other) citations for patents that were issued after 2000. These data indicate that patent-hybrid pairs that serve as an input to at least one *insect resistant* follow-on hybrid receive 1.3 additional citations (Table 8, column 2, significant at 5 percent); hybrids that serve as inputs for at least one *herbicide tolerant* follow-on hybrid receive 2.6 additional citations (Table 8, column 2, significant at 1 percent).

To examine whether self-citations are a good predictor for follow-on invention, we re-estimate the baseline regressions with count of self-citations as a dependent variables and indicator variables to distinguish *insect resistant* and *herbicide tolerant* follow-on hybrids. These estimates indicate that patents for hybrids with at least one *insect resistant* follow-on hybrid receive 1.9 additional self-citations (Table 9, column 2, significant at 5 percent), while patents for hybrids with at least one *herbicide tolerant* follow-on hybrid receive 3.4 additional citations (Table 9, column 2, significant at 1 percent). In these regressions estimates for *yields* and moisture are not significant (Table 9, column 2, with p-values of 0.170 and 0.134, respectively). In regressions on the same sample without controls for insect resistant and herbicide tolerant hybrids estimates for yields are statistically significant; implying that a 1 percent increase in yields is associated with 0.1 additional citations (Table 9, column 1). Excluding patents with more than 100 citations reduces the size of the estimate for *insect resistant* follow-on hybrids to 1.3 additional citations (Table 9, column 4, significant at 5 percent), and for *herbicide tolerant* follow-on hybrids to 2.2 additional citations (Table 9, column 4, significant at 1 percent).

3.8. 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.

3.9. Other indicators of patent quality: claims, patent renewal and foreign patent family members

Patent claims, which specify the technology space that is covered by a patent, are a standard measure for the size, and more specifically, for the scope of patented inventions (e.g., Branstetter and Sakakibara 2001; Lanjouw and Schankerman 2004). In the case of utility patents for plants, the first claim typically covers the seed of a plant, as well as the plants that grow from that seed. Additional claims cover traits of the plant, such as heat tolerance and disease resistance, breeding methods, or sweetness and other characteristics as a food product.[37] For example, Pioneer's patent US5,574,209 includes seven claims. 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*.

It is notable that USPTO 5,576,472 - the very next Pioneer patent - makes the exactly the same

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

seven claims for its hybrid *3375* using nearly the same language; its claim 7 references hybrid *3951* in place of *3375*, which this is most likely a typo due to cut-and-paste editing. Cutting and pasting text of successful patent applications appears to be a common practice among the patents in our sample; it may lead to a mechanical increase in claims.

On average, 269 patents for corn hybrids between 1985 and 2002 include 24.0 claims (Table 10). Across 13 breeder-attorney pairs in our data, the average number of claims ranges from 3.0 to 50.0 claims (Table 10). For 12 of 13 breeder-attorney pairs the number of claims per patent increases over time.[38] Comparisons of patent documents (in section 2.1 *Utility patents for hybrid corn*) suggest that patent attorneys may use successful patent applications as a template for future applications. The time patterns of increases in patent claims are consistent with this idea. Counts of claims increase over time, as long as a breeder works with the same attorney. For Pioneer patents, counts of claims 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). In 2000, when Pioneer switches to the outside legal firm McKee, Voorhees and Sease, counts of claims decline to 21.3 claims per patent in 2000, and then increase again to 24.4 in 2001.[39]

Another alternative measure of patent quality uses data on patent owners' decisions of paying renewal fees to keep their patents active to infer the private *value* of patents (Schankerman and Pakes 1986; Harhoff et al. 1999; Bessen 2008).[40] To examine renewal decisions, we collect data on the status of patents with respect to the payment of fees.[41] Nearly all patents in the sample are renewed to the full term, leaving little observable variation to estimate owners' valuation of patents. Among 269 patents for

[38] 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.
[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] 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 correlated with citations. Harhoff et al. (1999) find that 964 U.S. and German patents that were renewed to the full term were more heavily cited than patents that their owners had allowed to expire.
[41] Available at http://www.uspto.gov/patents/process/maintain.jsp, accessed June 2014.

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 in fact renewed to the full term (Table 11). A total of 36 patents were at least 8 years old in 2014; 36 of these patents (100 percent) were renewed after 8 years. Interestingly, DeKalb's foundational patent US4,629,819 was renewed at 4 and 8, but not 12 years.[42]

High renewal rates may be due, at least in part to the fact that renewal fees are low relative to R&D costs in plant breeding. 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. By comparison, Pioneer's parent company DuPont devoted half of its $1.4 billion research budget to agriculture, while DeKalb's parent Monsanto spent an unspecified share of its $1.1 billion budget to the development of new seeds (Associated Press, August 25, 2010).[43]

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, however, 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."[44] 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

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[42] Three of the five patents that were never renewed are patents that the USPTO issued to DeKalb in 1995, before DeKalb was acquired by Monsanto (US5,436,389, US5,444,177, and US5,451,705). Only two additional patents, for dent corn hybrids (assigned to the German *Kleinwanzlebener Saatzucht AG*) were not renewed for the full term.

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

[44] EPO case number T 2362/10 (European Case Law Identifier: ECLI:EP:BA:2014:T236210.20140121).

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.[45] 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.[46] We find that none of the 269 US patents issued for hybrid corn had a foreign patent family member.[47]

3. Conclusions

Although citations are the most popular control for unobservable variation in the quality of patents, research on strategic citations and on patent examiners has cast doubt on the usefulness of citations as a measure of quality. This paper has linked patents for hybrid corn with data on improvements in yields, as an objective measure for the size of the inventive step, to examine the link between citations and patent quality. This analysis reveals a substantial amount of variation in the size of the inventive step that is covered by individual patents, confirming the need to control for variation in the quality of patents. But the analysis also shows that citations are positively and robustly correlated with yields and other objective measures for the size of the inventive step. With the caveat that our data are based on a single,

[45] A similar ban was also imposed by Austria, France, Greece, Hungary and Italy (Davison 2010).
[46] Administrative court Braunschweig (Germany), case number 2 B 111/09.
[47] Data on patent families are available from the EPO at http://worldwide.espacenet.com, accessed on June 2014.

albeit economically important industry, our findings suggest that citations are an informative measure for the quality of patents.

One characteristic of this industry is that improvements have become subject to utility patents fairly recently (in 1985); this is a characteristic that it shares not only with other branches of biotechnology, but also more technologically distant fields, such as information technology and business models in finance. Our findings suggest that, in these industries, early patents may receive a larger number of citations – irrespective of the value of the innovation that they cover – because they establish patentable subject matter. Patent attorneys appear to cite these patents primarily as a signal that there is a precedent for a patent. We also find that *self*-citations can be a useful predictor for follow-on (or cumulative) invention in rapidly growing industries.

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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
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
Increase in yields per acre (in %)	-0.814	4.864	-0.509	-36.179	12.338
Increase in moisture (in %)	-0.246	5.262	0	-16.746	20.976
Hybrid covered by >1 patent	0.213	0.410	0	0	1
Patent covers >1 hybrid	0.203	0.403	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: Excluding patents with > 100 citations (N=310)					
Citations	3.626	4.916	2	0	34
Citations by patents issued after 2000	3.574	4.876	2	0	34
Examiner-added citations (after 2000)	1.716	3.218	1	0	34
Increase in yields per acre (in %)	-0.851	4.875	-0.513	-36.179	12.338
Increase in moisture (in %)	-0.263	5.300	0	-16.746	20.976
Hybrid covered by >1 patent	0.216	0.412	0	0	1
Patent covers >1 hybrid	0.206	0.405	0	0	1
Year of application (1985 + *t*)	13.226	2.276	13	4	17
Breeder: Pioneer (N=140)	0.452	0.499	0	0	1
DeKalb (N=137)	0.442	0.497	0	0	1
Monsanto (N=14)	0.045	0.208	0	0	1
Asgrow (N=8)	0.026	0.159	0	0	1
Other (N=11)	0.036	0.185	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. *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 difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid that was tested in the same field trials as the patented hybrid normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the water content of a corn hybrid at harvest relative to the highest-yielding comparison hybrid. The variable *> 1 patent* equals 1 if the same hybrid is covered by more than 1 patent; the variable *> 1 hybrid* equals 1 if the same patent covers more than 1 hybrid. *Breeder* refers to the patent assignee. Panel B omits five patents with more than 100 forward citations (see table 3 for a detailed description).

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

	OLS (1-3)			Poisson (4-6)		
	(1)	(2)	(3)	(4)	(5)	(6)
Yields	0.489**	0.491**	0.486**	0.737***	0.759***	0.785**
	(0.238)	(0.239)	(0.241)	(0.262)	(0.276)	(0.312)
Moisture		-0.009	-0.016		-0.071	-0.149
		(0.081)	(0.081)		(0.147)	(0.162)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10						
N	315	315	315	315	315	315
R-squared	0.554	0.554	0.554	0.627	0.628	0.632
Year FE	YES	YES	YES	YES	YES	YES
>1 patent FE	NO	NO	YES	NO	NO	YES
>1 hybrid FE	NO	NO	YES	NO	NO	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 bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. 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. Specifications (1)-(3) estimate OLS; specifications (4)-(6) 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 patent - hybrid pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 3 – PATENTS THAT ARE CITED MORE THAN 100 TIMES

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 difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid that was tested in the same field trials as the patented hybrid normalized by the yield of 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 – OLS AND POISSON, EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS, DEPENDENT VARIABLE IS FORWARD CITATIONS TO PATENT - HYBRID PAIRS

	OLS (1-3)			Poisson (4-6)		
	(1)	(2)	(3)	(4)	(5)	(6)
Yields	0.152***	0.156***	0.146***	0.181***	0.192***	0.177***
	(0.051)	(0.052)	(0.051)	(0.062)	(0.066)	(0.059)
Moisture		-0.019	-0.029		-0.033	-0.052
		(0.043)	(0.041)		(0.046)	(0.048)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10						
N	310	310	310	310	310	310
R-squared	0.117	0.117	0.153	0.083	0.084	0.114
Year FE	YES	YES	YES	YES	YES	YES
>1 patent FE	NO	NO	YES	NO	NO	YES
>1 hybrid FE	NO	NO	YES	NO	NO	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 bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. 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. Specifications (1)-(3) estimate OLS; specifications (4)-(6) 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 310 patent - hybrid pairs for 264 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 5 – POISSON, EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS,
CITATIONS BY PATENTS ISSUED AFTER 2000 (COLUMNS 1-3) AND EXAMINER-ADDED CITATIONS (COLUMNS 4-6)

	Citations by patents issued after 2000 (1-3)			Examiner-added citations (after 2000) (4-6)		
	(1)	(2)	(3)	(4)	(5)	(6)
Yields	0.180***	0.192***	0.177***	0.084**	0.080*	0.069*
	(0.062)	(0.066)	(0.059)	(0.041)	(0.044)	(0.041)
Moisture		-0.035	-0.054		0.012	-0.001
		(0.046)	(0.047)		(0.034)	(0.035)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10						
N	310	310	310	310	310	310
R-squared	0.083	0.084	0.115	0.104	0.105	0.140
Year FE	YES	YES	YES	YES	YES	YES
>1 patent FE	NO	NO	YES	NO	NO	YES
>1 hybrid FE	NO	NO	YES	NO	NO	YES

Notes: *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.The variable *yields* measures the improvement in yields (in bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. 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 310 patent - hybrid pairs for 264 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 6 – SUMMARY STATISTICS FOR HYBRIDS THAT SERVE AS INPUTS FOR FUTURE HYBRIDS, 1986-2005

		Mean	Std. Dev.	Median	Min	Max
Panel A: All patent-hybrid pairs (N=159)						
Citations		10.164	57.642	2	0	693
Self-citations		3.824	12.092	1	0	105
Citations by patents issued after 2000		8.478	50.084	2	0	621
Examiner-added citations (after 2000)		0.925	1.443	0	0	8
Increase in yields per acre (in %)		-1.256	5.438	-0.505	-36.179	9.229
Increase in moisture (in %)		-0.705	5.584	-1	-16.746	20.976
Hybrid covered by >1 patent		0.101	0.318	0	0	1
Patent covers >1 hybrid		0.126	0.333	0	0	1
Follow-on hybrid, insect resistant		0.358	0.481	0	0	1
Follow-on hybrid, herbicide tolerant		0.245	0.432	0	0	1
Year of application (1985 + *t*)		12.447	3.223	13	0	17
Breeder:	Pioneer (N=126)	0.793	0.407	1	0	1
	DeKalb (N=18)	0.113	0.318	0	0	1
	Monsanto (N=14)	0.088	0.284	0	0	1
	Other (N=1)	0.063	0.079	0	0	1
Panel B: Excluding patents with > 100 citations (N=155)						
Citations		3.297	4.319	2	0	23
Self-citations		2.503	4.068	1	0	19
Citations by patents issued after 2000		3.200	4.214	2	0	20
Examiner-added citations (after 2000)		0.929	1.446	0	0	8
Increase in yields per acre (in %)		-1.312	5.460	-0.505	-36.179	9.229
Increase in moisture (in %)		-0.748	5.646	-1.020	-16.746	20.976
Hybrid covered by >1 patent		0.102	0.305	0	0	1
Patent covers >1 hybrid		0.129	0.336	0	0	1
Follow-on hybrid, insect resistant		0.368	0.484	0	0	1
Follow-on hybrid, herbicide tolerant		0.252	0.435	0	0	1
Year of application (1985 + *t*)		12.742	2.672	13	4	17
Breeder	Pioneer (N=124)	0.800	0.401	1	0	1
	DeKalb (N=16)	0.103	0.305	0	0	1
	Monsanto (N=14)	0.090	0.288	0	0	1
	Other (N=1)	0.006	0.080	0	0	1

Notes: Data include 159 patents – hybrid pairs for 143 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* are citations coming from later patents owned by the same firm. *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 difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid that was tested in the same field trials as the patented hybrid normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the water content of a corn hybrid at harvest relative to the highest-yielding comparison hybrid. The variable > *1 patent* equals 1 if the same hybrid is covered by more than 1 patent; the variable > *1 hybrid* equals 1 if the same patent covers more than 1 hybrid. *Insect resistant* 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* 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. *Breeder* refers to the patent assignee. Panel B omits four patents with more than 100 forward citations (see table 3 for a detailed description).

TABLE 7 – POISSON, PATENT - HYBRID PAIRS WITH INFORMATION ON CUMULATIVE INVENTIONS, EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS (COLUMNS 3-4), DEPENDENT VARIABLE IS FORWARD CITATIONS TO PATENT - HYBRID PAIRS

	All patents (1-2)		Excluding patents with >100 citations (3-4)	
	(1)	(2)	(3)	(4)
Yields	1.066**	0.977*	0.125**	0.074**
	(0.514)	(0.520)	(0.057)	(0.033)
Moisture	0.043	-0.0044	-0.050	-0.075
	(0.215)	(0.216)	(0.052)	(0.054)
Follow-on GM hybrid, insect resistant		3.900*		1.376**
		(2.349)		(0.670)
Follow-on GM hybrid, herbicide tolerant		7.012***		2.633***
		(2.636)		(0.762)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10				
N	159	159	155	155
R-squared	0.859	0.872	0.189	0.310
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 bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* 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* 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 159 patent - hybrid pairs for 143 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 8 – POISSON, PATENT - HYBRID PAIRS WITH INFORMATION ON CUMULATIVE INVENTIONS, EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS, CITATIONS BY PATENTS ISSUED AFTER 2000 (COLUMNS 1-2) AND EXAMINER-ADDED CITATIONS (AFTER 2000) (COLUMNS 3-4)

	Citations by patents issued after 2000 (1-2)		Examiner-added citations (after 2000) (3-4)	
	(1)	(2)	(3)	(4)
Yields	0.126**	0.072**	0.032	0.036
	(0.059)	(0.033)	(0.027)	(0.031)
Moisture	-0.053	-0.076	-0.013	-0.012
	(0.052)	(0.053)	(0.017)	(0.016)
Follow-on GM hybrid, insect resistant		1.291**		-0.083
		(0.656)		(0.249)
Follow-on GM hybrid, herbicide tolerant		2.589***		-0.093
		(0.756)		(0.252)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10				
N	155	155	155	155
R-squared	0.184	0.303	0.157	0.159
Year FE	YES	YES	YES	YES

Notes: *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. The variable *yields* measures the improvement in yields (in bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* 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* 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 155 patent - hybrid pairs for 139 US utility patents issued between August 30, 1989 and March 8, 2005 in subclass 800/320.1 *Maize.*

TABLE 9 – POISSON, PATENT - HYBRID PAIRS WITH INFORMATION ON CUMULATIVE INVENTIONS, EXCLUDING PATENTS WITH MORE THAN 100 CITATIONS (COLUMNS 3-4), DEPENDENT VARIABLE IS SELF-CITATIONS TO PATENT - HYBRID PAIRS

	All patents (1-2)		Excluding patents with >100 citations (3-4)	
	(1)	(2)	(3)	(4)
Yields	0.099*	0.058	0.115**	0.071*
	(0.052)	(0.043)	(0.053)	(0.040)
Moisture	-0.069	-0.111	-0.067	-0.088*
	(0.077)	(0.074)	(0.052)	(0.053)
Follow-on GM hybrid,		1.903**		1.290**
insect resistant		(0.892)		(0.585)
Follow-on GM hybrid,		3.423***		2.174***
herbicide tolerant		(0.965)		(0.677)
Standard errors clustered at the level of hybrids. *** p<0.01, ** p<0.05, * p<0.10				
N	159	159	155	155
R-squared	0.625	0.688	0.256	0.382
Year FE	YES	YES	YES	YES

Notes: The dependent variable *self-citations* measures the sum of self-citations to a patent - hybrid pair. The variable *yields* measures the improvement in yields (in bushels per acre) over existing hybrids, calculated as the difference in bushels per acre between the patented hybrid and the highest-yielding comparison hybrid in the same field trials normalized by the yield of the highest-yielding comparison hybrid. *Increase in moisture* measures the relative moisture level of the patented hybrid to the highest-yielding comparison hybrid. *Insect resistant* 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* 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 159 patent - hybrid pairs for 143 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*.

TABLE 10 – PATENTS AND CLAIMS BY BREEDER AND ATTORNEY

Breeder	Attorney	# of patents	Average # of claims
Pioneer	Pioneer (in-house)	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 11 – 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

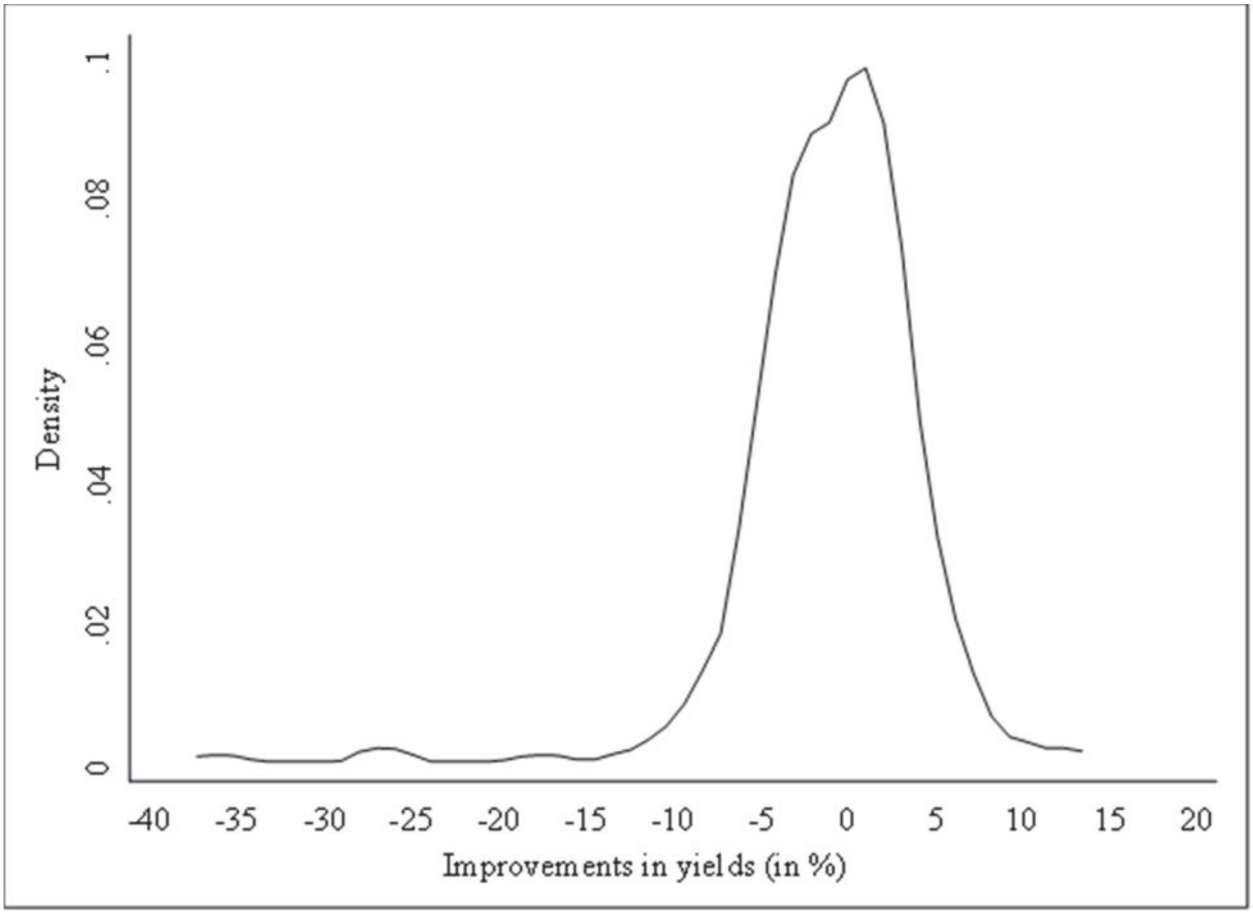
Notes: Data include 269 U.S. utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize*. Data on patent renewals is available at https://ramps.uspto.gov/eram/patentMaintFees.do and was accessed in 2014. The decision on patent renewal 12 years after issue can therefore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

TABLE 12 - FIELD TRIAL DATA

Institution conducting the Field Trial	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

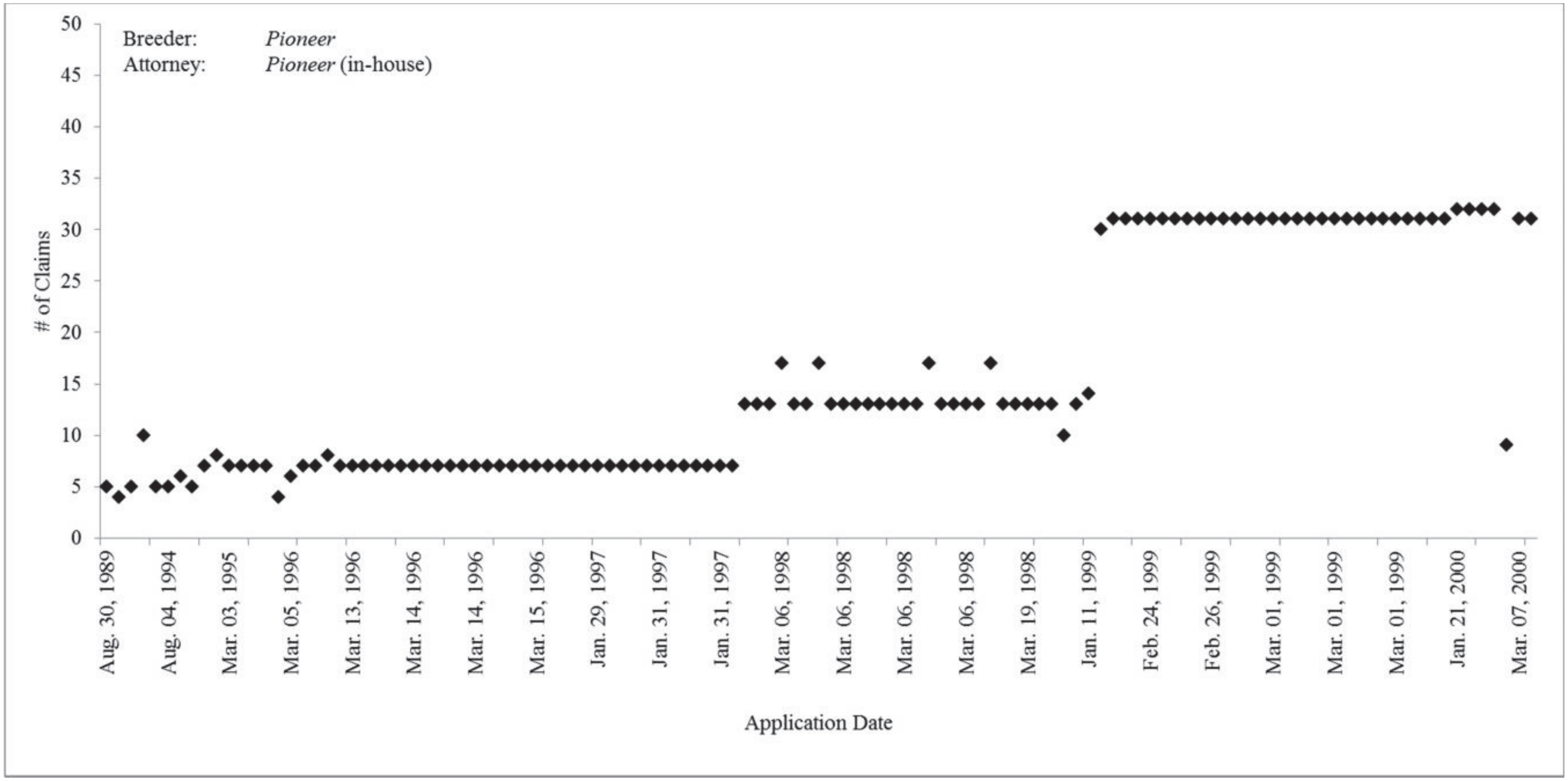
Notes: Field trial reports are available from the following website: http://www.ca.uky.edu/cornvarietytest/; http://corn.agronomy.wisc.edu/HT/Default.aspx; http://www.gov.pe.ca/photos/original/af_06cornguide.pdf; http://www.gocorn.net/v2006/CornReports/2001cornreport/2001performancetrials.html; http://www.gocorn.net/v2006/CornReports/2002cornreport/2002performan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

FIGURE 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 patents with more than 100 citations from the sample produces no noticeable differences in the distribution of yields; yields for these patents are listed in Table 5. 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.

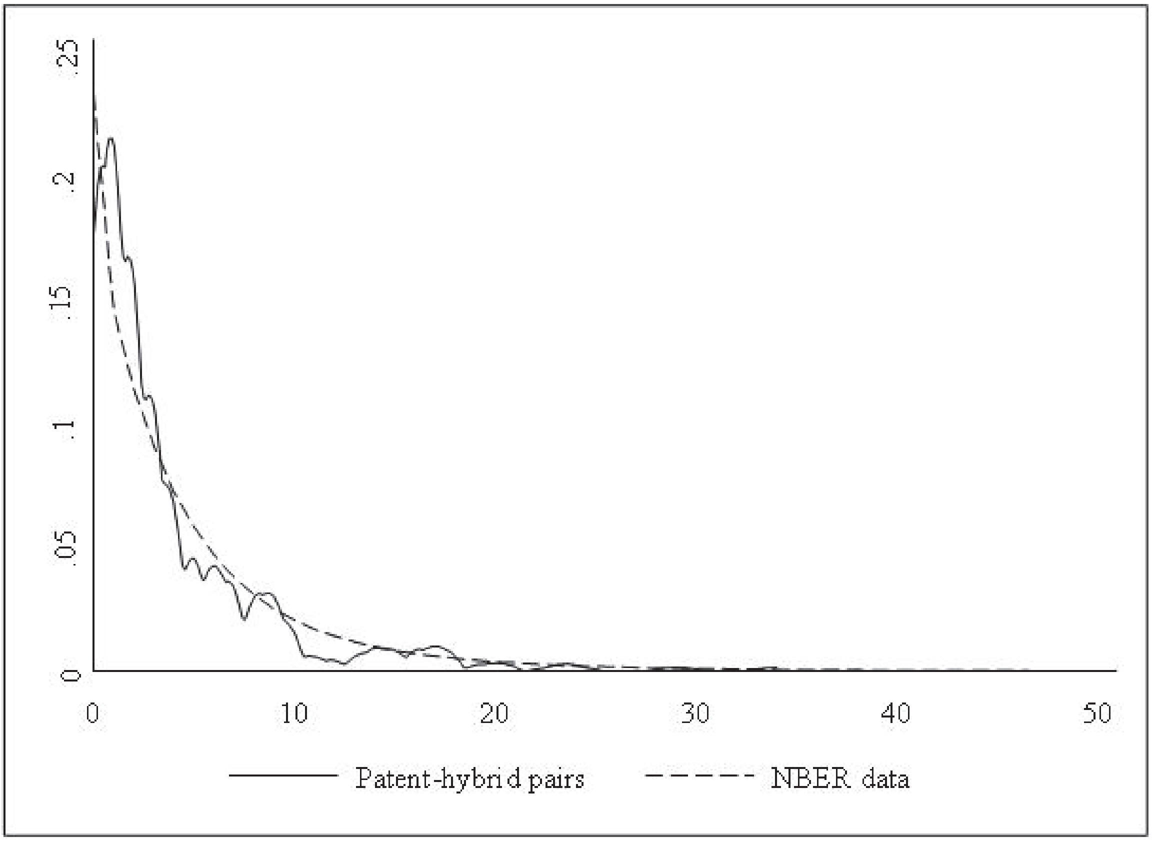
FIGURE 2 – NUMBER OF CLAIMS INCLUDED IN THE PATENT BY APPLICATION DATE



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

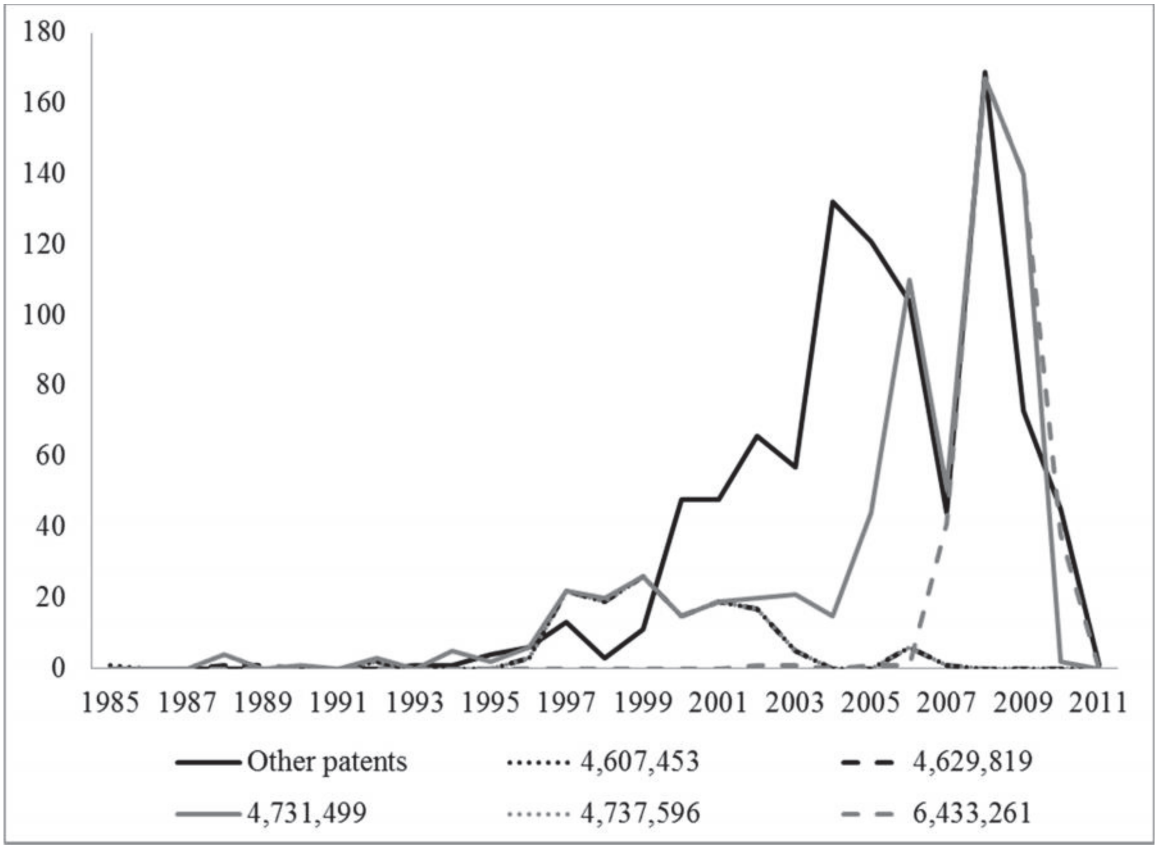
SUPPLEMENTAL APPENDIX – FOR ONLINE PUBLICATION ONLY

FIGURE A1 – CITATION COUNTS FOR PATENT-HYBRID PAIRS WITH <100 CITATIONS



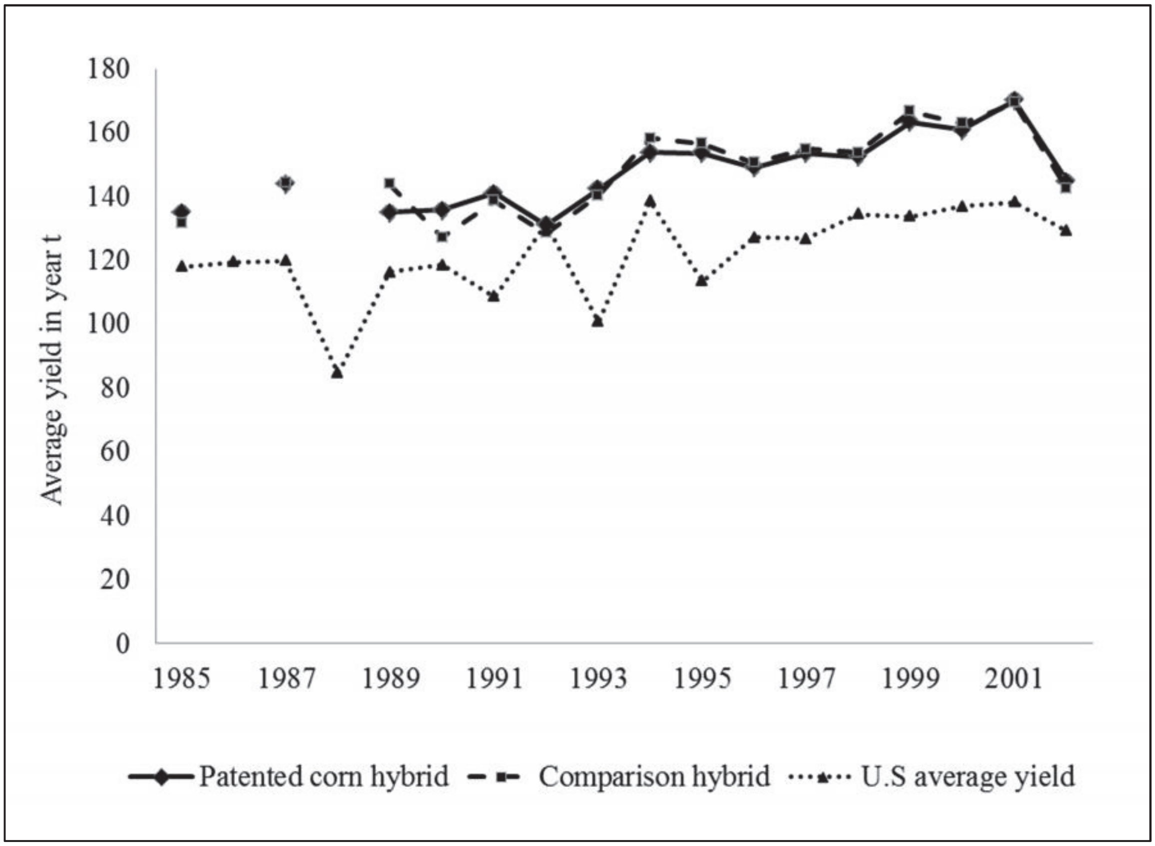
Notes: Citation counts for 310 patent – hybrid pairs for 264 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 *Maize* (available at www.uspto.gov). Excluding patents US4,607,453 (136 citations), US4,629,819 (137 citations), US4,731,499 (693 citations), US4,737,596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

FIGURE A2 – CITATIONS PER YEAR FOR PATENT-HYBRID PAIRS



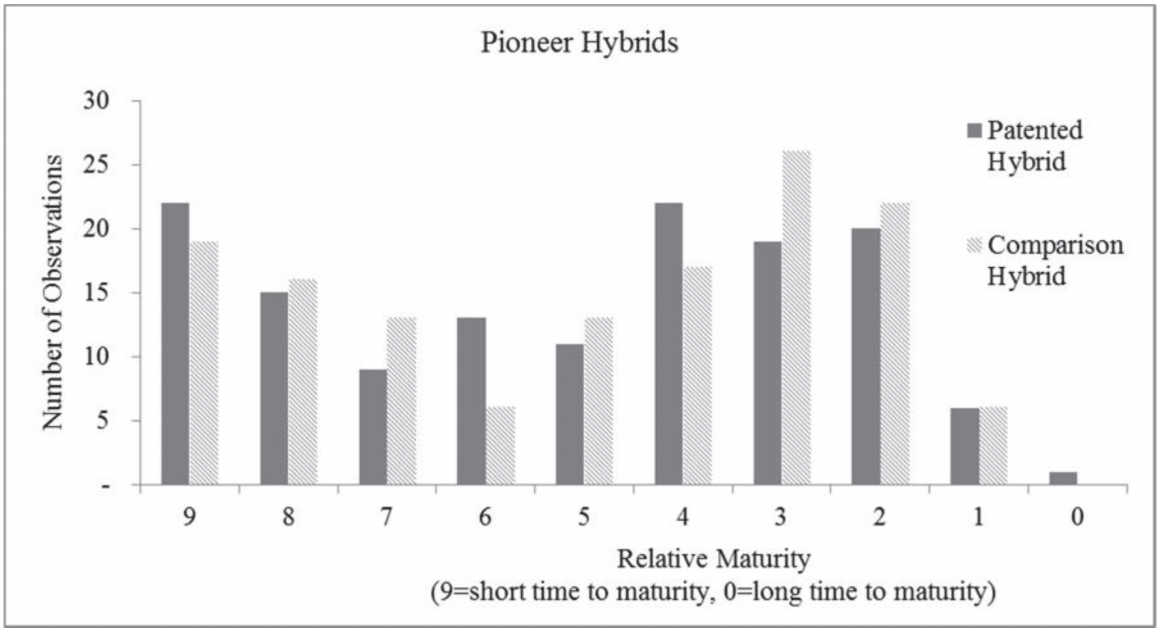
Notes: Citation counts per year for 315 patents – hybrid corn pairs for 269 US utility patents issued between August 26, 1986 and March 8, 2005 in subclass 800/320.1 Maize (available at www.uspto.gov). *Other patents* counts the sum of citations per year to 310 patent-hybrid pairs that received fewer 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.

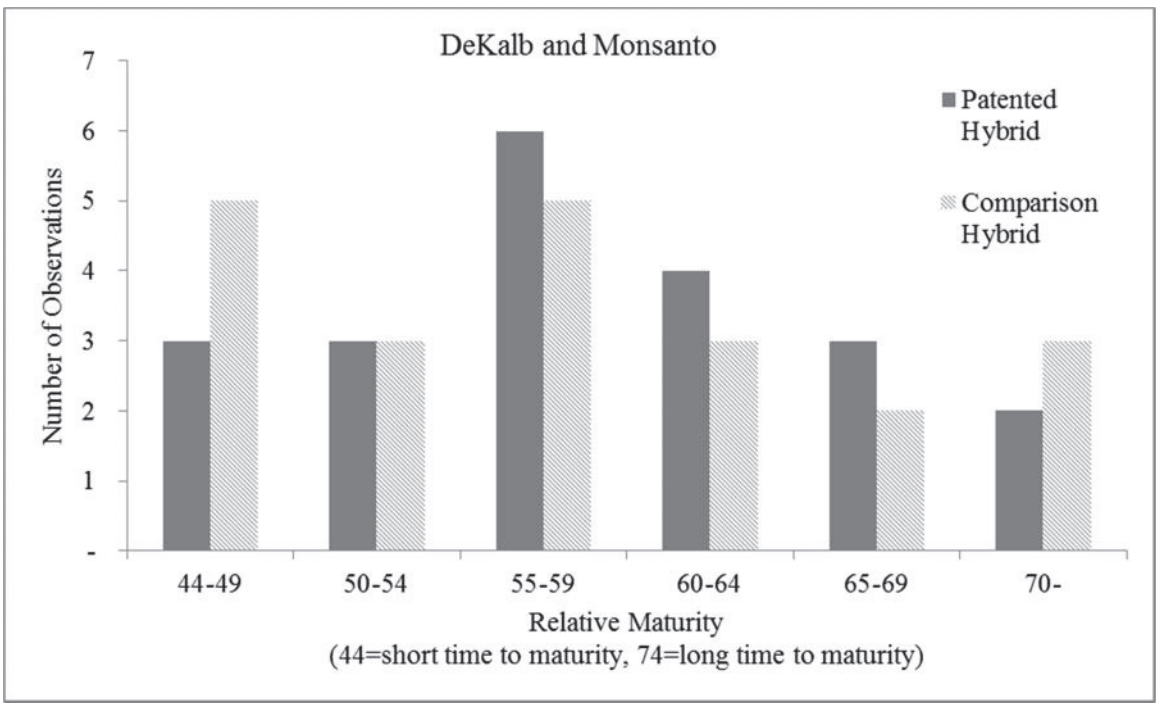
FIGURE A3 – AVERAGE YIELD PER YEAR, NEWLY PATENTED CORN HYBRIDS VERSUS COMPARISON HYBRIDS VERSUS U.S. AVERAGE YIELDS



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).

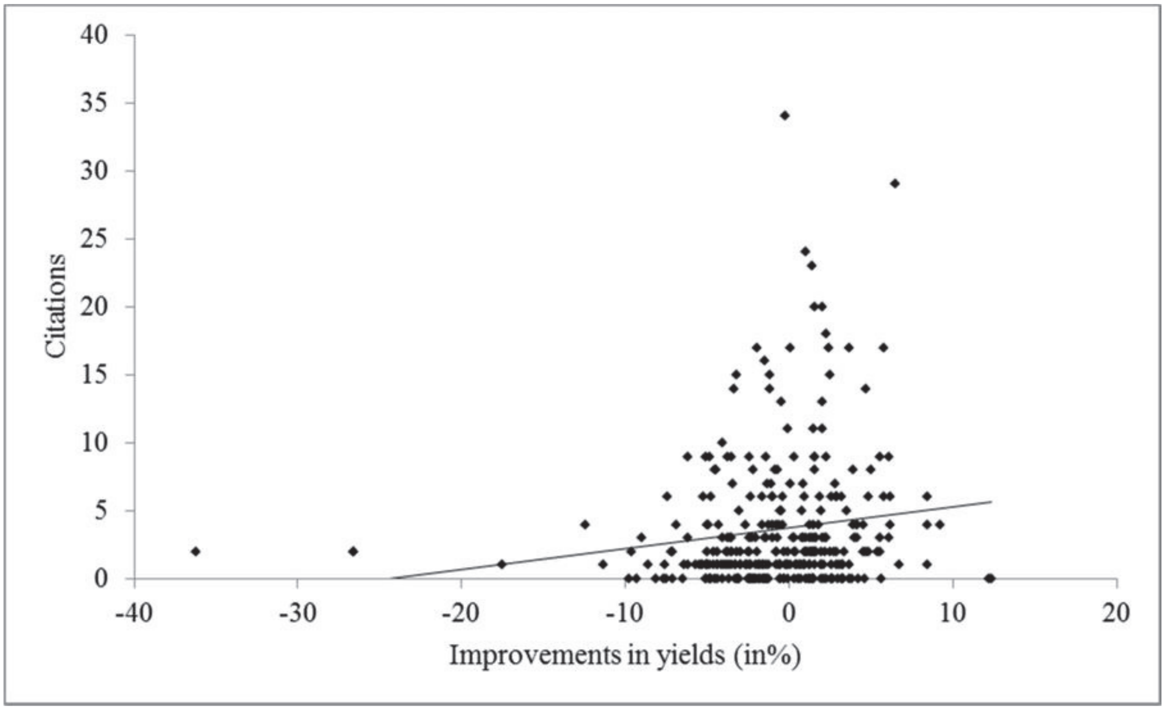
FIGURE A4 – DISTRIBUTION OF RELATIVE MATURITY
FOR NEWLY PATENTED AND COMPARISON HYBRIDS





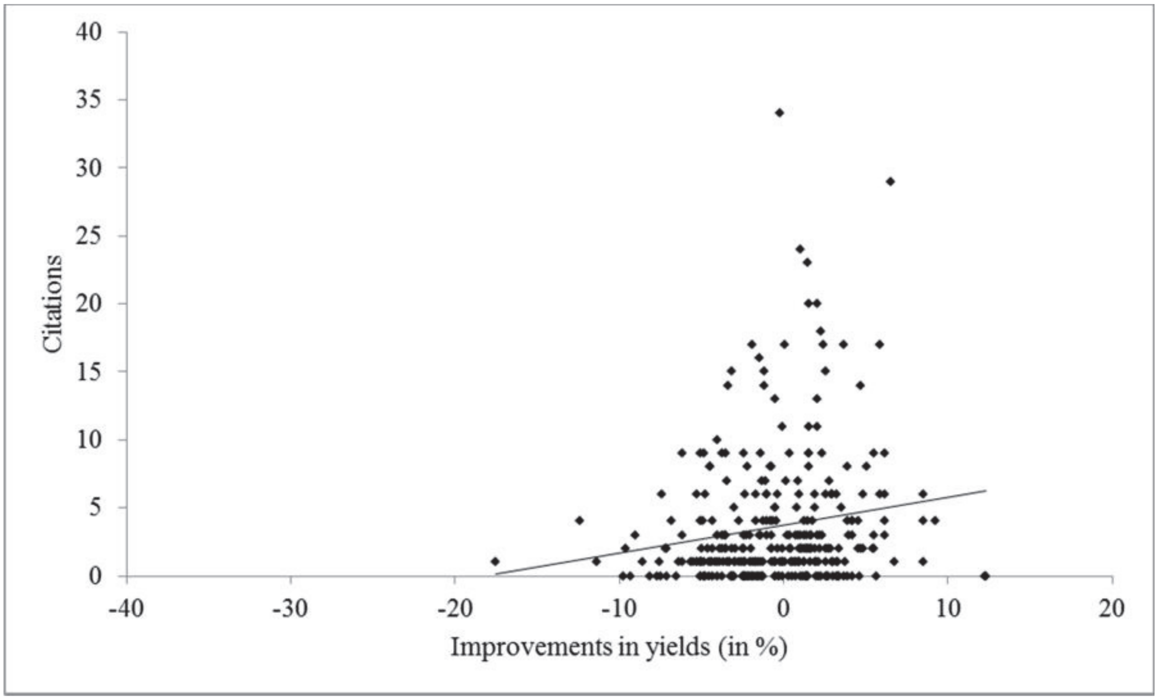
Notes: Information on relative maturity is encoded in the product name of new hybrids. The second digit of Pioneer's hybrid name identifies its relative maturity on a scale from 0 (very full) to 9 (very short). See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming 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,
EXCLUDING PATENTS WITH >100 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 3.755, and a slope of 0.152 (with a standard deviation of 0.057).

FIGURE A6 – CITATIONS AND IMPROVEMENTS IN YIELDS, EXCLUDING PATENTS WITH >100 CITATIONS AND HYBRIDS WITH < -20% IMPROVEMENTS IN YIELDS



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. Excluding patents US6,362403 (36.2% decrease in yields), US5,859,319 (26.6 decrease in yields), and US6,037,530 (26.6 decrease in yields). The line fits a linear regression without controls, with an estimated intercept of 3.759, and a slope of 0.206 (with a standard deviation of 0.071).