PATENTS, CITATIONS, AND INVENTIVE OUTPUT- EVIDENCE FROM HYBRID CORN

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JULY 24, 2011

This paper examines field trial data for patented corn hybrids to quantify the relationship between patents, citations, and the magnitude of inventive output. Field trial data for 256 patented corn hybrids between 1986 and 2005 suggest that most patented corn hybrids do not improve significantly on prior art: 58 percent of patented hybrids produce less corn than existing hybrids. Citations, however, are highly correlated with the magnitude of inventive output: A 10 percentage point increase in yields is associated with 1.9 additional citations.

We wish to thank Bronwyn Hall, Eric Hilt, David Mowery, Heidi Williams, Brian Wright, as well as seminar participants at Berkeley and Stanford for helpful comments. Christopher Sung provided excellent research assistance.

A common concern with patent data is that "inventions that are patented differ greatly in 'quality,' in the magnitude of inventive output associated with them" (Griliches 1990, p. 1669). Counts of citations are the most commonly used measure to control for the quality of patented inventions, but there is little systematic evidence on the relationship between citations and the size of innovations. This paper uses field trial data for patented new corn hybrids to examine whether counts of citations by later patents are a meaningful proxy for the size of innovation. Specifically, we match patented improvements in hybrid corn with field trial data for new hybrids to measure the size of improvements in crop yields and revenues.

Corn is one of the world's leading food crops, and has accounted for up to a quarter of harvested acreage in the United States throughout much of the 20th century. U.S. breeders began to hybridize corn seeds after 1908, when plant scientists George H. Shull and Edward M. East crossbred two inbred (homozygous) plants, and found that the first filial (F1) generation plant generated more corn than open-pollinated varieties.[1] Shull and East's inbreds, however, were stunted and did not produce enough seeds to make their discovery commercially viable. In 1917, Donald F. Jones created the first double cross (F2) hybrids by crossing two F1 lines; Jones' F2 hybrid out-performed open-pollinated varieties and produced enough seeds to be commercially viable. In 1923, Henry A. Wallace, who later founded the Pioneer Seed Company, introduced *Copper Cross*, as one of the first commercial hybrid seeds.[2] In 1933, hybrid seed was planted on less than one percent of U.S. corn acreage. By 1939, its share had risen to almost half. By 1960, nearly all U.S. corn acreage was hybrid seed (Griliches 1957, 1960; Olmstead and Rhode 2008, pp. 64-67). Advances in yields, which are the focus of this analysis,

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[1] Homozygous inbred plants carry the same alleles (forms) of a gene; they are simultaneously female and male, and can therefore pollinate themselves and create identical offspring. When two homozygous inbreds are crossed, the all of the offspring share the same combination of alleles.

[2] 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 in 1921 (Funk Bros. Seed Co., 1940; Fitzgerald 1990). In the 1960s and 1970s, improvements in inbred plants and methods of cultivations increased yields from F1 plants sufficiently to allow breeders to market F1 instead of F2 lines (Kloppenberg 2005, Sutch 2008). Today F1 seeds account for nearly all corn seed planted in the United States.

determined the onset and speed of adoption (Griliches 1957).[3]

Improvements in hybrid corn became subject to utility patents after 1980, when the U.S. Supreme Court's ruled in favor of Ananda M. Chakrabarty, a microbiologist at General Electric. Chakrabarty had developed the genetically-engineered *pseudomonas* bacterium to break down crude oil into substances that could serve as food for aquatic life, and was denied a patent by the USPTO. In 1980, the Supreme Court decided that the *pseudomas* bacterium should be patentable because the "relevant distinction is not between living and inanimate things" but between naturally existing and human-made substances (*Diamond vs. Chakrabarty*, 447 U.S. 303 (1980)). In 1985, the USPTO *de facto* extended utility patents to sexually propagated plants, such as hybrid corn (*Ex parte Hibberd*, 227 USPQ 443 Bd. Pat. App. & Int).[4] This unilateral decision by the USPTO was affirmed by the U.S. Supreme Court in 2001, when the Court decided that the same seed could be protected simultaneously by a utility patent and a plant variety protection certificates, an alternative type of intellectual property rights (IPRs), which the Plant Variety Protection Act had created in 1970 to provide IPRs for seeds (*J.E.M. Ag Supply vs. Pioneer Hi-Bred International*, 534 U.S. 124).[5]

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[3] Griliches (1957) examines cross-sectional differences in the use of hybrid seed corn and explains differences in the lag with which seed producers adopt hybrid corn based on market density and marketing costs. Griliches (1960) documents that adoption followed an S-shaped growth curve across regions: the rate of adoption was slow at first, accelerated to a peak at approximately mid-point, and then decelerated. Suri (2011) shows that lower rates of hybrid corn adoption among farmers in Kenya can be explained by heterogeneities in the benefits and costs of adopting hybrid corn. Estimates from a correlated random coefficient model using survey data for 1997 and 2004 suggest that farmers with the highest estimated gross returns to adoption face high costs of adopting the technology due to poor infrastructure.

[4] *Ex parte Hibberd* established that corn plants are patentable under regulation 35 U.S.C. 101, which states that "(w)hoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefore, subject to the conditions and requirements of this title." Regulation 35 U.S.C. 112 specifies the requirements for reporting: the "specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor of carrying out his invention."

[5] On December 24, 1970, Congress passed the Plant Variety Protection (PVP) Act, which authorized the US Department of Agriculture to issue PVP certificates, which provide exclusive marketing rights for new varieties of sexually propagated plants (seeds) that are "uniform, stable, and distinct from all other varieties." Fungi, bacteria, and first-generation (F1) hybrids were initially excluded (Strachan 1992). *Distinctness* requires that the variety differs by one or more identifiable morphological, physiological or other characteristics (which may include processing or product characteristics, such as, milling and baking characteristics in the case of wheat); *uniformity* implies that any variations are describable, predictable and commercially acceptable; and *stability* in the sense that the variety, when sexually reproduced or reconstituted, will remain unchanged with regard to its essential and distinctive characteristics with a reasonable degree of reliability (7 U.S.C. Sec. 2401 cited in U.S. Court of Appeals, Fifth Circuit, *Delta Pine vs. Peoples'*

The USPTO granted the first utility patent for a corn hybrid on August 26, 1986. Until 2005, all patents for hybrid corn reported field trial data on yields in bushels per acre and moisture levels. Yields are the bottom-line measure for improvements. Data on moisture levels allow farmers to calculate the expected revenue from new hybrids; moisture levels above 15 percent decrease the value of corn by increasing drying costs and the risk of spoilage.[6]

Field trial data for 256 patented corn hybrids indicate that most patented corn hybrids produced less corn than comparable hybrids that were already in production: 58.20 percent of hybrids that were patented between 1986 and 2005 produce less corn than the *highest-yielding* comparison hybrids; 55.86 percent generate less income. 22.66 percent of hybrids produce less corn than the *average* comparison hybrid. On average, patented hybrids yield 1.06 percent less corn and 1.06 percent less income than the highest-yielding existing hybrids.

Field trial data also indicate that the size of improvements in yields and income decline over time. More than 70 percent of hybrids patented after 1998 produce less corn than existing varieties, compared with 47 percent before 1998, and more than 63 percent produce less income after 1998, compared with 53 before 1998.[7] On average, hybrids that were patented between 1998 and 2005 yield

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Gin 694 F.2d 1012 Jan. 3, 1983). A 1994 Amendment to the PVP Act extended PV protection to F1 seeds (effective in 1995, Janis and Kesan 2002 p. 746). Varieties that have been sold or used in the United States for more than 1 year or abroad for more than 4 years are also ineligible. PVP certificates remain in effect for 18 years from the date of issue. Breeders are required to submit 2,500 sample seeds (with germination rates of at least 85) when the application is filed, these sample sees are stored at the National Seed Storage Laboratory in Ft. Collins, CO (Strachan 1992). In 1992, protection required a filing fee of $250 and an examination fee of $1,900, as well as the deposit of 2,500 viable seeds (Strachan 1992). “The ‘importance’ or ‘value’ of characteristics to the productivity of the crop are not considered when making novelty decisions. Therefore, ‘cosmetic’ traits, those which do not contribute to the productivity of the crop, can be used to distinguish among varieties. Some breeders argue that basing judgments on cosmetic traits trivializes a PVP certificate” (Strachan 1992). Breeders do not appear to use PVPs to protect first or second generation hybrid corn: By November 2008, Pioneer had applied for 549 PVP certificates for corn. But almost all appear to cover inbred lines rather than hybrids. In contrast to utility patents, PVP certificates are narrower, covering only one variety, and they include no claims. In comparison, plant patents include a single claim. PVP certificates do not allow breeders to prevent competitors from using a new variety in their breeding program.

6 See Uhrig and Maier (1992) for a detailed discussion of the effects of moisture. Other characteristics influence the quality of hybrid corn seeds primarily through their effects on yields: time to maturity, resistance to pest and diseases, drought-tolerance, and adaptability to soil quality. Field trials control for such characteristics by growing comparable crops under identical conditions. In addition to yields and moisture, we also collect data on variation in the relative maturity of hybrid corn, which we can collect from the naming practices of Pioneer hybrids (www.pioneer.com/home/site/ca/products/product-naming-system).

7 A total of 134 hybrids were patented up to 1998 and 122 between 1999 and 2005.

2.10 percent less corn and 2.00 percent less income than existing hybrids.

Controlling for alternative factors, including variation in the number of days that hybrids need to mature, or in disease resistance, cannot explain these results. Most importantly, corn hybrids vary according to the climatic conditions that they require to thrive, and in particular in the number of days with adequate growing conditions that they require to mature (e.g. Griliches 1957, 1960; Hicks and Thomison 2004, pp. 482-484 and 493-495).[8] As a first cut, we collect information on variation in the relative maturity of Pioneer hybrids between 1997 and 2005, when the company encoded information on relative maturity in the names of new seeds. These data indicate no systematic changes in relative maturity over time.[9] The average hybrid corn plant in our data has a relative maturity index of 5.03 before 1998, 5.31 after 1998 and 5.19 across the sample on a scale from 0 to 9 (very full to very short relative maturity), with no discernible decrease in maturity over time. Data on disease/pest resistance indicates significant improvements in 11 of 16 diseases, Common Rust, Eye Spot, Goss's Wilt, Gray Leaf Spot, Northern Leaf Blight, Southern Leaf Blight, Stewart's Wilt, Corn Lethal Necrosis, European Gibberella Ear Rot, European Corn Borer 1st and 2nd generations but no improvements in resistance to 5 diseases, including Southern Rust, Maize Dwarf Mosaic Virus, Anthracnose Stalk Rot, Diplodia Ear Rot, and *Fusarium*- Ear-and-Kernel Rot.

These results suggest that plant breeders may use utility patents for strategic reasons, to protect

[8] Guidelines for selecting hybrid corn recommend that farmers first "select hybrids with maturity ratings appropriate for your geographic area or circumstances" to allow corn to reach physiological maturity before the first frost that kills it. Then, "Step 2, Choose hybrids with consistently high yields across a number of locations and/or over years…Choosing a hybrid because it possesses a particular trait, such as big ears, many kernel rows, deep kernels, prolificacy, or upright leaves will not ensure high yields; instead, look for stability in performance across environments. ("Steps for Selecting Hybrid Corn", Ohio State Extension, Publication AGF 125-95, http://ohioline.osu.edu/agf-fact/0125.html, accessed June 16, 2011)

[9] Another omitted characteristic of corn hybrids relates to the sugar content of corn, which increases the value of harvested corn per weight. This issue became after 2005 when the *Renewable Fuel Program* of the Energy Policy Act mandated renewable fuel use in gasoline, which is typically corn-based, to reach 7.5 billion gallons by calendar year 2012 (nearly double compared with 2005 levels, Westcott 2007). In 2005/06 ethanol accounted for 14 percent of U.S. production in field corn, compared with 55 percent for animal feed, Westcott 2007. Corn-based ethanol production had increased gradually from 1.6 billion gallons in 2000/01 to 3.5 billion gallons in 2005/06, but was expected to increase to nearly 8 billion gallons by 2015/16. As a result, the share of ethanol in corn use was projected to increase drastically, and without being anticipated by the USDA and breeders, after 2006 to 31 percent by 2016/17 (Westcott 2007), leading to an increase in the price of corn, and more than likely also shifting R&D efforts towards crops with high sugar-content. Hybrids in our data, which include patent grants only until 2005, are not affected by this policy change.

themselves from litigation or extract licensing revenues. In the hybrid corn sector, rapid increases in patenting coincide with a period of consolidation when Monsanto acquired nearly all plant breeders in the industry except Pioneer. In February 1996, Monsanto formed a joint venture with DeKalb Genetics, acquiring a 40 percent stake in the producer of hybrid corn seed (*New York Times*, Feb. 2, 1996, p. D4). In late September 1996, Monsanto began the process of acquiring Asgrow, its partner in developing Roundup-Ready soybeans, and a seed company with a long history in developing vegetables, and most recently soybeans (*New York Times*, Sept. 25, 1996, p. D3, Fernandez-Cornejo 2004, pp. 31, 34).[10] The transaction was completed by 1998 and they soon began to market *Roundup-ready* hybrid corn, which could withstand the application of Monsanto's powerful *Roundup* (glyphosate) herbicide to destroy weeds. In January 1997, Monsanto agreed to purchase Holden's Foundation Seeds for one billion dollars (Charles 2001, p. 197; *New York Times*, Jan. 7, 1997, p. D8).[11] On May 11, 1998, Monsanto announced that it would pay $2.3 billion for the remainder of DeKalb; the transaction was completed on December 1, 1998 (*New York Times*, May 12, 1998, p. D2; Dec. 1, 1998, p. C4). In 1997, Monsanto introduced the DeKalb's *Yield Gard* hybrid corn, which is resistant to the European corn borer.

After 1997, only two players remained in the industry, Monsanto/De Kalb, and Pioneer, which

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[10] Asgrow was amenable to a partnership with Monsanto, because its researchers had created squash that was engineered to resist a virus, and required a fragment of DNA, the 35S promoter that Monsanto researchers had isolated and patented in the 1980s; Monsanto paid $240 million for Asgrow's corn and soybean business, and Asgrow acquired the rights to use the 35S promoter (Charles 2001, p. 195). "Monsanto's acquisition of Agrow, and its restrictive contracts with many other smaller seed companies, forced people to radically revise their estimates of what germ plasm was worth. It appeared that elite germ plasm was just as rare and difficult to create from scratch as new and valuable genes. Seed companies never had earned substantial profits. But it suddenly became clear to many in the industry that they had become very valuable indeed. Control over seed companies meant access to billion-dollar markets. "(Charles 2001, p. 197)

[11] Charles (2001, pp. 198-199) describes the importance of Holden's Seed Foundation: "Until the 1960s the nation's mom-and-pop seed companies had relied on breeding programs at agricultural universities, which regularly distributed, free of charge, new corn hybrids. But those publicly funded breeding programs gradually fell behind the efforts of Pioneer and DeKalb and closed down. Ron Holden stepped into the gap. Holden's mainained a small but well-run breeding program that delivered new 'inbred' lines that became the parents of hybrid seed sold by family-owned seed distributors all over the country. The smaller compaines often relied exclusively on Holden's for their seed stock; larger enterprised such as Golden Harvest or Dobelers' or even DeKalb used parental lines from Holden's to supplement their own breeding programs. Only Pioneer refused to use any material from Holdens. When one added it all up, corn lines from Holden's were the imemdiate ancestors fo 40 percent of all the corn grown in the United States."

had resisted Monsanto's attempts at purchasing it. In August 1997, Du Pont acquired a 20 percent stake in Pioneer; in October 1999, Du Pont purchased the remaining 80 percent (Fernandez-Cornejo 2004, p. 33).

In 1999, Pioneer held 42 percent of the seed market, compared with Monsanto's share of 12 percent (Figure A1). In 2003, Pioneer introduced its first bio-engineered hybrid; *Herculex*, which was resistant to the European corn borer. By the mid-2004, however, Monsanto had pushed ahead of Pioneer as a market leader (Fernandez-Cornejo 2004), possibly fuelled by "surging crop prices, which allowed farmers to buy the latest bug-resistant, herbicide-tolerant corn" (Associated Press, August 25, 2010).[12]

If breeders patent for strategic reasons, and many patents do not improve on prior art, measures for the quality of patented inventions become particularly important (e.g., Griliches 1990, p. 1669; 1998, pp. 296, 308). With the availability of electronic data sets like the NBER patent citations data (Hall, Jaffe, and Trajtenberg 2001), counts of citations by later patents have emerged as the standard measure of patent quality. There is however, to date no quantitative evidence to prove that citations are positively correlated with the magnitude of improvements, which typically cannot be measured. As a result, existing studies compare citations count for "important" patents with citations to control patents. Most prominently, Trajtenberg (1990) showed that citations counts are positively correlated with the estimated social surplus that 456 improvements in CAT scanners created over time (Trajtenberg 1990).[13] Citations are also positively correlated with changes in the stock market valuations of firms that own the cited patents (Hall, Jaffe, and Trajtenberg 2005).

Field trial data for hybrid corn establish a large, and statistically significant correlation between

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[12] In 2010, DuPont devoted half of its $1.4 billion research budget to agriculture, compared with Monsanto's $1.1 billion budget (Associated Press, August 25, 2010).

[13] Similarly, Carpenter, Narin and Woolf (1981) compare citations for 100 "important" patents between 1969 and 1974 with 102 control patents that had been issued in the same year. In their study, important patents are defined as patents that they match with "the 100 most significant technical products" selected the journral *Industrial and Research Development* in 1969 and 1970. These 100 patents were cited 494 times between 1968 and 1974, compared with 102 control patents that were issued in the same years and were cited only 208 times.

counts of citations and the magnitude of improvements in patented plants. For example, OLS and negative binomial regressions imply that a 10 percentage point increase in yields is associated with 1.9 additional citations; a 10 percentage point increase in income is associated with 2.5 additional citations when the comparison is made with respect to the highest-yielding comparison hybrid. A 10 percentage point increase in yields is associated with 2.4 additional citations when the comparison is made with respect to the average comparison hybrid. Results are robust to controlling for the age of patents, time- and firm-fixed effects, linear and quadratic time trends, and negative binomial specifications.

Counts of citations are also positively correlated with the breadth (or scope) of patents, measured by the number of claims that define the subject matter of a patent, but this correlation is not statistically significant. Empirical analyses have used the number of claims as a proxy for the breadth (or scope) of patent grant (e.g., Sakkakibara and Branstetter 2001), and claims have been proposed as an additional, complementary measure for the importance of patented inventions (Lanjouw and Schankerman 2004). The number of claims per utility patent of hybrid corn increases over time even though the size of improvements becomes smaller, as breeders add claims to their own, firm-specific templates of patent applications.

We also compare citations with renewal data as an alternative measure of patent quality.[14] 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. Renewal data for U.S. patents between 1985 and 1991 indicates that renewals and citations are highly correlated (Bessen 2008). Among 256 corn hybrids in our sample, 98 percent were renewed after 4, 8, and 11 years, suggesting that renewal fees around $8,000 for a patent renewed to full term, are too small relative to the large research budgets of plant breeders to elicit information about the value of patents.

We also test whether breeders may strategically choose field trials that maximize the magnitude

[14] In addition, data on prize-winning innovations (Moser 2003, 2011) have been proposed as measures for the quality of patents. To the best of our knowledge, no comparable data can be collected for corn hybrids. All-American Seed Selection Prizes are awarded to garden varieities for sweet corn, but no reliable data exist on prize-winning in field corn.

of their improvements. To measure this, we link two patented hybrids that are not directly compared to one another through at least one other comparison hybrid that is included in both patent applications. A total of 172 patented hybrids can be paired with existing hybrids. Indirect comparisons are subject to more measurement error than field trial that are directly reported on patent documents and were conducted under identical growing conditions, but results are suggestive. In indirect comparisons, only 35 percent of patented hybrids produce more corn and 35 percent generate more income than existing hybrids.

UTILITY PATENTS FOR CORN HYBRIDS

Our data consist of 256 pairs of utility patent grants and field trial data between August 26, 1986 and March 8, 2005, when Pioneer, one of the two large firms in the industry, stopped reporting moisture levels as a share of total weight.[15] This window of analysis precedes the Energy Policy Act of July 29, 2005 (Pub.L. 109-58), which mandated an increase in the amount of biofuel in U.S. gasoline. Since ethanol is typically produced from corn, the Act increased the price of corn, and raised the value of corn with extremely high sugar content; this change in relative prices may have changed the direction of innovation.

For patent grants up to 2005, we can observe citations for a minimum of five years, which is how long it takes for counts of citations in the NBER patent data set to reach their highest level (Hall, Jaffe, Trajtenberg 2001). Application dates for patent grants between March 1986 and March 2005 range from February 21, 1985 to September 9, 2002. The average patent grant occurs 28 months after the application, with a median of 24 months and a standard deviation of 15 months. We use application dates to measure the timing of invention.

Between August 26, 1986 and March 8, 2005, the United States Patent and Trademark Office

[15] The switch occurred at a time when Pioneer was losing market share to Monsanto, which had created high-performing bio-tech seeds.

granted a total of 1,181 utility patents in the subclass 800/320.1 *Maize*. We focus on field corn (as opposed to garden variety sweet corn or pop corn), which accounts for more than 98 percent of acreage and nearly all research activity of large commercial breeders.[16] A total of 256 patents in this subclass cover inventions in hybrid field corn; 118 of these patents cover both a hybrid and at least one parent inbred plant. For example, USPTO 6,864,409 for the DeKalb states "inbred wddq1 has been used to prepare an F1 hybrid corn plant, designated dk642," and compares dk642 with established hybrids. The hybrid dk642 is included in the data; it yields 6.55 percent more corn than the established hybrid dk636. USPTO 6,864,409 includes 29 claims and covers 10 additional hybrids; hybrid dk636 is covered by 2 additional patents and cited by 4 later patents. An additional 488 patents cover inbred corn lines only. Other patents include genetic modifications, such as the "terminator gene" for "Methods for maintaining sterility in plants (USPTO 5,717,129). A total of 245 patents for corn

[16] 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. Another reason to focus the analysis on field corn, is that traits that determine the quality of sweet corn are less tractable than traits for field corn. Sweetness is the most important, other important traits, in addition to high germination and yields, important traits of sweet corn are texture, aroma and kernel color (Lertrat and Pulam 2007, p.27). In 2004, the world's top four leading producers were the United States (4.12 million MT, Lertrat and Pulam 2007, p. 27), Mexico (0.63 million MT), Nigerio (0.58 million MT) and France (0.50 million MT). Sweetness is affected by the amounts of sugar and starch in the endosperm; to improve sweetness, breeders select mutants that produce high sugar levels in the kernel endosperm. Most of sugary-type sweet corn breeding work for temperate regions has been done in the United States, with Dantings Early (1844) as the earliest named variety. Golden Bantam, released in 1902, became of the most important open-pollinated varieties. Many new hybrid varieties, such as Jubilee and Silver Queen (the most popular roadside market sweet corn) Golden Cross Bantum, Early Sunglow, Merit, Seneca Chief, Bonanza, and Earlivee have been developed and marketed (Lertrat and Pulam 2007, p. 28). Sugar-enhanced (*se*) varieities, such as Seneca Arrowhead have been developed by Seminis Seeds, Cookham, Co. and Meza Maize, Inc.. Supersweet (sh_2), which contains 29.9% sucrose, the highest amount (compared with 3.5% for field corn), was first developped by John Laughnan ant the University of Illinois in the 1950s (Lertrat and Pulam 2007, p. 28). In the early 1980s a successful marketing campaign by Abbott and Cobb Inc. increased the usage from 2 to more than 90% (Lertrat and Pulam 2007, p. 28). Breeders, such as Xtra-Tender ® (Illionois Foundation Seed Inc.), Gourmet Sweet Brand®, and Multiswwets®, at Sweet Breed ® (Harris Moran Seeds), or Triple Sweet ® (Rogers Seed), Table Sweet® (Mesa Maize) to protect their improvements. We have searched our data for 256 field trial utility patents for these breeders and varieities, but our data include neither. Subclass 800/320.1 groups together field corn, sweet corn, and pop corn but the three types of crops are recorded separately in the classifiction system for Plant Variety Protection (PVP) certificates as field corn, field corn (F1), popcorn, sweet corn, and sweet corn (F1) http://www.ars-grin.gov/cgi-bin/npgs/html/pvplist.pl. Neither Monsanto nor Pioneer (or Du Pont) are listed as breeders of sweet corn or pop corn for PVP certificates; they do not advertise these crops on their websites, and key word searches for firm names and "sweet corn" or "popcorn" yield no results. All American Selection (AAS) ward-winning varieties of field (sweet) corn, such as *How Sweet it is* (All American Selection 1986) and *Honey Select* (2001) and Indian Summer (2000) are developed by small independent breeders, such as xxx and xxx instead of the larger firms like Du Pont or Monsanto. These breeders do not patent varieties, but mechanisms to increase the sugar content of their corn (e.g., Lertrat and Pulam 2007)

hybrids (96 percent) list *maize* as their primary subclass. The remaining 11 patents list *maize* as a secondary subclass.[17] In comparison, 68 percent of the 488 patents for inbred corn lines list subclass 800/320.1 as their primary subclass compared with only 14 percent of 437 patents for 'other' inventions.

In addition to claims, the number of hybrids that are covered by the same patent, as well as the number of other patents that cover the same hybrid can be used as measures for the scope or breadth of patents; regressions will include these measures as alternative controls. The average patent in our data covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids.[18] The average hybrid is covered by 1.2 patents but one hybrid is covered by 3 patents (Table 1).[19]

Few breeders apply for utility patents until the mid 1990s

Between 1985 and 1993, only a handful of breeders applied for utility patents for hybrid corn each year (Figure 1, utility patents for corn, granted by March 2005), measured at the date of application). In 1994, the number of hybrid corn patents increased rapidly to 13 patents, including 7 applications by Pioneer, 5 by DeKalb, and 1 by Sandoz. In 1995, the number of patent applications dipped to 7 (all assigned to Pioneer). After 1995, the number of patent applications increased smoothly to reach 5 in 1999. After 1999, patent applications for corn hybrids declined to 29 in 2000, and 31 in 2001. The low number of patent applications in 2002 is due to truncation. Expanding the data to include patent grants by October 2010 increases the number of applications to 33 (instead of 7) in 2002, 29 (instead of 0) in 2003, 30 (instead of 0) in 2004, and 67 (instead of 0) in 2005.

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[17] Out of these 11 patents, 7 patents list 800/271 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization* - *Method of breeding using gametophyte* as the primary subclass and there is one patent each that lists 800/263 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization* - *Breeding for altered carbohydrate composition*, 800/267 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization* - *Molecular marker is used*, 800/274 *Via a male sterility genetic trait*, and 800/275 *Method of using a plant or plant part in a breeding process which includes a step of sexual hybridization* - *Method of breeding maize* as the primary subclass.

[18] There exists significant variation between firms. While Pioneer patents always only cover 1 hybrid, DeKalb patents cover between 1 and 10 hybrids with an average of 1.37 hybrids per patent.

[19] The average Pioneer hybrid is protected by 1.02 patents, while the average DeKalb hybrid is covered by 1.35 patents.

Time trends in patenting for inbreds and other inventions closely mirror time trends in patenting for hybrid corn, with slightly larger numbers of applications for inbred corn lines and other inventions in hybrid corn in all years. Patents for inbred corn lines reach 13 for the first time in 1989, when Pioneer applies for 12 patents and Holden's Foundations Seeds applies for 1 patent. After a brief dip to 6 application in 1990, application for inbred corn lines increase to 19 in 1993 and 18 in 1994.

Interestingly, the onset of increasing numbers of patent applications for inbreds and other inventions precedes the onset of increasing numbers for corn hybrids, by 2 years, reaching a first peak of 52 patents for other inventions in 1995 and 62 patents for inbred patents in 1996. After a brief dip in 1996 and 1997 respectively, patents for inbred corn and other inventions reach another local peak with 70 and 91 patents respectively in 1999, and decline afterwards.

Why do breeders patent corn hybrids?

The delayed onset of patenting is consistent with archival evidence on internal deliberations within the American Seed Trade Association (ASTA), which reveal that breeders of hybrid corn initially opposed the creation of formal property rights for sexually-propagated plants. In debates leading up to the Plant Variety Protection (PVP) Act of 1970 breeders of hybrid corn argued that patents would not benefit invention and "inevitably end up adding undesirable controls."[20] Intuitively, breeders of hybrids may be less dependent on formal protection *ex ante* because the desirable characteristics of a hybrid do not appear reliably in offspring, and typically cannot be replicated without access to the parent (inbred) lines.[21]

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[20] "Report of the Hybrid Corn Subcommittee. " Folder XV-Misc, Delta and Pine Land Company Records. Box 85, The "Report of the Hybrid Sorghum Subcommittee" went further, arguing protection "might even retard progress in plant breeding." Also see Kloppenberg, 2005

[21] This is consistent with historical evidence on an increase in the share of chemical innovations that firms chose to patent in response to an exogenous decrease in the effectiveness of secrecy. Analyses of exhibition data indicate that the large majority of 19th century (more than 80 percent) were not patented and that patenting rates varied strongly across industries. Patenting rates for chemical innovations increased after scientific advances lowered the effectiviness of secrecy, both over time and relative to other industries (Moser 2012). For contemporary firms, survey data indicate that firms in most industries, except for pharmaceuticals, prefer secrecy to patenting (e.g., Cohen, Nelson and Walsh 2002).

Data on plant variety protection (PVP) certificates confirm that hybrid corn breeders also delayed adopting this alternative type of property right until the early 1980s, while breeders of soybeans began to apply for PVP certificates as early as 1971; in the 1990s, counts of PVP certificates per year converged for the two crops (Dhar and Foltz 2007, also see Janis and Kesan 2002).

If secrecy provides an effective alternative, why did breeders of corn hybrids begin to use patents? One potential explanation is that the effectiveness of informal protection declined as breeding programs became more systematic and some breeders began to patent inbreds that they had developed based on their rivals' hybrids.[22] For example, one of the first patent grants to DeKalb (USPTO 4,594,810 granted June 17, 1986) covers a new inbred corn line, which DeKalb had developed by crossing two unpatented hybrid lines of Pioneer. Another patent grant to DeKalb in the same year covers the hybrid DK672 (USPTO 4,607,453 granted August 26, 1986), which DeKalb developed by crossing its own inbred HBA1 with B73Ht, "developed by Iowa State... available to the public." In 1995 DeKalb was granted another patent for a cross between its own inbred MBUB and B73 HT "a public line available through Iowa State University " (USPTO 5,444,177, issued August 22, 1995). In 1999, DeKalb's inbred 3000200 (USPTO 5,969,212 granted October 19, 1999) incorporated material from Pioneer hybrid 3475 and Holden Foundation Seeds, LH 132; DeKalb's inbred 5014422 (USPTO 5,994,631 granted November 30, 1999) included Pioneer hybrid 3293 as one parent.[23]

Breeders appear to incorporate both patented and unpatented varieties of rivals in the new lines that they develop. For example, DeKalb's inbred 01CSI6 (USPTO 5,777,196 granted July 7, 1998) is a descendent of the Pioneer hybrid 3779; DKalb's inbred 2003929 (USPTO 5,856,614 granted January 5, 1999) is a descendent of the Pioneer hybrids 3615 and 3790, (USPTO 4,731,499 granted March 15, 1988).

[22] Taba, Ebergard, and Polak (2004, p. 104), however, state "It is extremely difficult to extract an inbred line once it has been hybridized."

[23] In comparison, most conventional (non-GMO) hybrids include genetic material from a small number of open-pollinated varieties such as *Reid*.

FIELD TRIAL DATA ON IMPROVEMENTS IN YIELDS, MOISTURE, AND OTHER CHARACTERISTICS

Since 1986, breeders of hybrid corn have adopted the practice of including information from field trials, including yields and moisture levels, in their patent applicants. Breeders report these comparisons voluntarily to establish the novelty of their plants, and they are able to choose the comparison plants. The USPTO does not check information in patent applications but misrepresentations would immediately invalidate a patent and breeders can count on competitors to conduct competing trials to verify their reports (Interview with Patent Examiner Gary Benzion, October 26, 2009). We will show below that changes in yields over time match changes in average yields in the United States, but also report evidence to suggest that breeders choose comparison plants strategically to increase the size of their improvements.

Field trials compare the performance of pairs of hybrids under identical growing conditions and in the same location. Locations are typically listed as “all the hybrids’ adapted growing areas” (USPTO 5,5022,72 for Pioneer hybrid 3563) or “locations around the United States” (USPTO 5.449,855 for DeKalb hybrid DK743). Among the 256 patents in our sample, only 2 include explicit data on locations. Field trials for Pioneer’s U.S. patent 4,731,499 (Pioneer hybrid 3790) were conducted in 8 test station across 6 U.S. states and one Canadian province: Bowling Green, Ohio; Woodstock, Ontario, Canada; Willmar Minnesota; Huron, South Dakota; Janesville, Wisconsin; Alma, Michigan; Mankato, Minnesota; and North Platte, Nebraska. Tests for Pioneer’s USPTO 4,737,596 (Pioneer hybrid 3471) were conducted in 13 tests stations across 9 states: Johnston, Iowa; Princeton, Illinois; Algona, Iowa; Bowling Green, Ohio; Carrollton, Missouri; Garden City, Kansa; Huron, South Dakota; Marion, Iowa; New Holland, Pennsylvania; North Platte, Nebraska; Shelbyville, Illinois; Windfall, Indiana; and York, Nebraska. An additional four patents report only the number of locations for their field trials, without revealing locations: U.S. patents 6,506,964; 6,506,965; and 6,512,167 – all

assigned to Rustica Prograin Genetique – report that performance data are based on "multilocation analysis of 15 locations." U.S. patent 6,646,188, assigned to Euralis, reports "multi-location analysis in 19 locations".

Yields are reported as bushels harvested per acre planted, normalized to a moisture level of 15.5 percent. Moisture levels are reported as the share of weight at harvest that is water. Corn at harvest has a high moisture level, especially following rain or an early frost. Corn with high moisture levels at harvest is costly to dry or rots in storage, and as a result sells at a discount beyond the actual share of corn that is water. To reduce moisture, farmers use fans and heaters to dry the corn; corn has to be dried in a slow process at low heat to avoid cooking so that farmers typically incur additional inventory costs (Uhrig and Maier 1992). In addition to moisture levels, other characteristics of hybrid corn, such as time to maturity, resistance to pest and diseases, drought-tolerance, and adaptability to soil quality are captured indirectly through their effects on yields.

To measure income, we follow the standard practice of assuming a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15 percent.[24] For example, Pioneer's new hybrid 3375 (USPTO 5,576,472 granted November 19, 1996, Figure 2, left patent) yields 181.1 bushels per acre and has a moisture level of 21.9 percent. This implies an income per acre of $407.20. In comparison, Pioneer's existing hybrid 3394 yields 172 bushels per acre and has a moisture level of 20.5 percent. This implies an income per acre of $386.78, equivalent to an increase of 5.28 percent (Figure 2, left patent).

We use two types of comparisons to measure the magnitude of improvements in hybrid corn, self-reported and indirect comparisons. In self-reported comparisons, breeders report field trial comparisons with existing hybrids. For example, Pioneer's new hybrid 3375 (USPTO 5,576,472, Figure 2, left patent) yields 181.1 bushels per acre. In comparison, Pioneer's existing hybrid 3394

[24] Price data from the USDA National Agricultural Statistics Service, available at www.nass.usda.gov.

yields 172 bushels per acre. This implies an increase in yields of 5.29 percent (Figure 2, left patent).

The data include a total of 726 self-reported comparisons; the average new hybrid is compared with 2.8 existing hybrids in self-reported comparisons (Table 2). As a first step, we measure the magnitude of inventions by comparing the new hybrid with the highest-yielding existing hybrid that is listed as a comparison plant.

To test whether breeders strategically report comparison plants that maximize the magnitude of the invention that they report to the USPTO we construct an additional set of indirect comparisons that were not reported to the USPTO but can be established by linking the new hybrid through another hybrid with a comparison hybrid that was not reported to the USPTO. For example, Pioneer's hybrid 3491 (USPTO 5,731,496 granted March 13, 1996, Figure 2, right patent) yields 165.2 bushels per acre and is compared to Pioneer's hybrid 3394, which yields 164.7 bushels per acre, implying an 0.3 percent increase in yields in self-reported comparisons. Pioneer's hybrid 3375 is also compared to hybrid 3394 (USPTO 5,491,295 granted November 22 1994, Figure 2, left patent), and we use this link to establish an indirect comparison between hybrid 3491 and 3375, which implies that 3491 produces 4.74 less corn than the existing hybrid 3375.[25] We are able to establish a total of 835 indirect comparisons for the 256 new hybrids in our data; on average a new hybrid can be linked with 3.3 existing hybrids in indirect comparisons.

Checks for the yield data

Although breeders may choose the most favorable trial, there is no reason to believe that they would systematically misreport the results of a given trial. The close correspondence in time trends between U.S. average corn yields and reported field trial data (Figure 3) also indicate that changes in field trial yields are a good measure of increases in performance.

[25] The relative yield of hybrid 3491 to hybrid 3394 times the relative yield of hybrid 3394 to hybrid 3375 equals (165.2/164.7)*(172.0/181.1) = 0.9526, implying a 4.74 percent decrease in yield.

U.S. averages vary around 120 bushels per acre, while yields in the field trial data remain around 140 bushels per acre, or 15-20 percent higher (Figure 3). More generally, changes in yields over time are similar for the matched field trial data and U.S. averages. Yields in field trials fluctuate less across year (with a variance of 144 in field trials, compared with 201 in U.S. averages) because growing conditions are more controlled in the field trials, but changes over time in field trials reported on the patent applications closely mirror changes in U.S. averages.

New plants are also customarily tested by independent experiment stations. We use data from the annual reports of the Kentucky Hybrid Corn Performance Tests between 1996 and 2009 to verify yields that breeders report on patent documents.[26] Hybrids for 17 direct comparisons were tested in Kentucky (Figure A2).

Correlation coefficients between yields on USPTO patents and in Kentucky field trials are 0.44 for yields and 0.38 for income, indicating a significant positive, but imperfect relationship (Figure A3, A4). Differences may be due to the fact that field trials are conducted in different locations and under different climatic conditions, so that two field trials for the same plant may not yield the same results. This is less problematic for the self-reported comparisons, which compare two plants in the same trial, but creates measurement error for the indirect comparisons, which compare plants across trials.

Counts of citations by later patents

To measure citation counts for the 256 hybrids in our sample, we search U.S. patents between January 1, 1986 and December 31, 2010 for references to the patent number of the 256 hybrids. This allows us to observe a minimum of 5 years of citations history for each patent.

The average patent for hybrid corn receives 7.55 citations between 1985 and 2010 (Table 1, Figure 4). In comparison, the average patent in NBER patent data (Hall, Jaffe, Trajtenberg 2001)

[26] Experiments are run by the University of Kentucky (www.ca.uky.edu/cornvarietytest/).

receives 3.0 citations within the first 5 years after the patent grant, 5.3 citations within 10 years, and 7.3 citations within 25 years.[27]

Five foundational patents are cited more than 100 times each

Two patents, for which DeKalb applied in 1985, are cited 136 and 137 times, respectively. DeKalb's patent USPTO 4,607,453 (filed on February 21, 1985, and granted on August 26, 1986) covers a

> Novel F1 hybrid corn plants DK 672, novel seeds of the hybrid, seeds produced by cultivation of the hybrid, cells which upon growth and differentiation produce the novel hybrid and a method to produce the novel hybrid are disclosed. DeKalb's patent 4,629,819 (filed on April 26, 1985, and granted on December 16, 1986) covers F1 hybrid corn plants DK 524, seeds produced by cultivation of the hybrid, and plant cells which upon growth and differentiation produce the novel hybrid.

Both of these patents are very likely cited so many times because they were the first patents after *re Hibberd* that were granted by the USPTO, and they are cited independently of their yields and other characteristics. In fact, most DeKalb patents cite Hibberd's patent along with the early patents that were issued to DeKalb to establish the patentability of their inventions.

After 1985, DeKalb did not apply for any additional patents for hybrid corn until 1990, when it applied for one patent (Figure 6, USPTO 5,589,605, granted on December 31, 1996 for hybrid EXP 748).

Similarly, two patents for which Pioneer applies in 1987, seven years before the company begins to patent systematically, receive a large number of citations. Pioneer's first patent USPTO 4,731,499 (for Pioneer hybrid 3790, granted on March 15, 1988) is the most cited patent in our data, with a total of 551 citations:

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

Number: 4,731,499
Title: Hybrid corn plant and seed
Inventor: Puskaric, et al.
Date Issued: March 15, 1988
Filed: January 29, 1987
Inventors: Carrigan; Lori (New London, MN); Puskaric; Vladimir (Woodstock, CA)
Assignee: Pioneer Hi-Bred International, Inc. (Johnston, IA)

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

Claim: What is claimed is: 1. Hybrid corn seed designated 3790. 2. A hybrid corn plant and its plant parts produced by the seed of claim 1. 3. Corn plants and the seed thereof regenerated from tissue culture of the hybrid corn plant and plant parts of claim 2. 4. A hybrid corn plant with the phenotypic characteristics of the hybrid plant of claim 2.

In a section entitled, “background,” this patent application includes a description of the process of breeding hybrid corn (Appendix Data); nearly all patents for corn hybrids that follow it include a similar description. Pioneer’s second patent in 1987 USPTO patent 4,737,596 (for Pioneer hybrid 3471, produced by crossing two proprietary Pioneer inbred corn lines, granted on January 29, 1987) is cited by 139 later patents. This patent, as well as nearly all other patents, includes the same description of the corn breeding process as Pioneer’s foundational patent for hybrid 3470.

USPTO patent 6,433,261, for the inbred corn plant 89AHD12 and “hybrid genetic complements of the inbred corn plant 89AHD12”, received 212 citations.

Claims as a Measure for the Scope (Breadth) of Patents

Claims, which define the scope of protection by specifying the matter that is subject to the utility patent, have been proposed as another measure for the quality of innovations (e.g., Lanjouw and Schankerman 2004). While other types of intellectual property rights cover only one trait (plant patents

for asexually reproduced plants under the PP Act of 1930) or no claims (under the PVP Act of 1970), utility patents can include a large number of claims. Each utility patent includes at least one claim, which typically covers the seed of the plant, as well as plants with the phenotypic characteristics of plant grown from that seed.[28] Additional claims cover plant traits, such as heat tolerance and disease resistance, breeding methods, or characteristics as a food product. We include claims as a measure for the scope of patents in regressions of citations counts on improvements in yields and other characteristics of hybrid corn.

Renewal Decisions as an Alternative Measure for the Quality of Patented Inventions

Nearly all patents in our data, 98 percent of all hybrid corn patents, were renewed to full term (Table 3).[29] Such high renewal rates may be due to the fact that the marginal costs of renewing a patent are small, relative to the enormous research expenditures of plant breeders. The USPTO introduced renewal fees to keep patents active on December 11, 1980. Renewal fees are $980 to keep a patent active at 4 years after the grant, $2,480 at 8 years, and $4,110 at 11 years. These fees are, however, negligible in comparison to the research budgets of major breeders, which account for nearly all hybrid corn patents. In 2010, for example, Pioneer's parent company DuPont devoted half of its $1.4 billion research budget to agriculture, while DeKalb's parent Monsanto devoted an unspecified share of its $1.1 billion budget to the development of new seeds (Associated Press, August 25, 2010).[30]

Among 256 patents of hybrid corn in our data, only 71 patents were at least 12 years old in 2011 and could have been renewed for the full term; 66 of these patents (93 percent), were renewed to full term. A total of 224 patents were at least 8 years old in 2011; 218 of these patents (97 percent) were

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[28] Breeders deposit specimen of these seeds with the American Type Culture Collection (ATCC) "an independent, private, nonprofit biological resource center (BRC) and research organization whose mission focuses on the acquisition, authentication, production, preservation, development and distribution of standard reference microorganisms, cell lines and other materials for research in the life sciences." http://www.atcc.org/About/tabid/138/Default.aspx

[29] Data on renewal fees and renewal decisions from www.uspto.gov.

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

renewed after 8 years; 251 patents (98 percent) were renewed after 4 years (Table 3).

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

RESULTS

Of 256 patented, only 107 (42 percent) produced more corn than existing hybrids (Table 2). The largest improvement in yields is 10 percent, but the data also include a hybrid that produces 25 percent less than existing hybrids (Figure 5). Data on improvements in income per acre confirm the relatively small magnitude of inventive output. Only 113 of 256 new hybrids (44 percent) produce more income than existing hybrids (Table 2).

These findings are robust across examiners and assignees. A total of nine primary patent examiners granted the 256 patents in our sample; two examiners granted 189 and 34 patents, respectively (Table 5). Estimates for the size of improvements are roughly comparable across examiners.

Patents are assigned to eight different breeders. The top two breeders, Pioneer and DeKalb,

produced 129 and 110 respectively (Table 6). For Pioneer, the estimates for the magnitude of inventive output are negative, with -2.4 percent for yields and -2.2 percent for income. In comparison, estimates for DeKalb/Monsanto are close to zero and slightly positive for yields, at 0.3 percent, and slightly negative for income at -0.1 percent. For both firms, the magnitude of improvements declines over time (Figure 6).

Gradual decline in the size of innovations over time

The data also reveal a decline in the magnitude of inventions over time. The gradual nature of this decline is consistent with the idea that yields approach a natural upper limit. For example, there is no evidence of a trend break in the years of Monsanto's aggressive acquisition policies (1994-1996) even though the absolute number of patents increased dramatically during this period.

Breeders choose comparison plants that magnify improvement

Data for 172 indirect comparisons, which we establish by linking new hybrids to other hybrids not reported on the patent, suggest that only 35 percent of new hybrids produce more corn or income than existing hybrids (Table 2). Although indirect comparisons are likely to be measured with some error, these results are suggestive. Comparisons of the distribution of self-reported and indirect comparisons confirm that breeders consistently choose comparison plants that increase the magnitude of their improvement over existing hybrids (Figure 7).

There is no evidence of statistically significant differences over time between self-reported and indirect comparisons; both series exhibit a decline over time from about 6 percent in 1989 to -4 percent in 2000 (Figures A5 and A6).

Claims

Data on claims indicate that the number of claims varies across firms, and increases over time. Across all years and breeders, the average patent includes 24.22 (Table 1). Over time, the mean number of claims per patent increases from 6.71 in 1985 to 30.86 in 2002 (Figure 8). Breeders appear to develop templates for their claims and expand their templates to add new claims over time. The average patent of DeKalb includes 32.27 claims; which cover the inbred parents of the hybrid, along with the hybrid itself, which is the main subject matter of the patent (Figure 9). In comparison, the average patent of Pioneer covers roughly half the number of claims, at 16.58 claims per patent, which typically only cover the hybrid itself, and not its inbred parents. 102 of DeKalb's 110 total patents cover inbred parents, in addition to the hybrid seed.

Claims are only weakly correlated with the number of hybrids covered by the same patent (Figure 10). A total of 19 in 256 patents (7.42 percent) protect more than one hybrid; the average patent protects 1.25 hybrids. Across all hybrids, the correlation between claims and the number of hybrids that are protected by a patent is 0.1111. Eighteen of the 19 patents that protect multiple hybrids are assigned to DeKalb; the remaining patent is assigned to the French seed company Euralis.

The data also indicate that claims are positively correlated with the number of patents that cover the same hybrid (Figure 11). Forty of 256 patented corn hybrids (16 percent) are covered by two or more patents; the average hybrid is covered by 1.20 patents, 28 hybrids are covered by 2 patents, 12 hybrids are covered by 3 patents. Across all hybrids, the correlation between claims and the number of patents that cover the same hybrid is 0.3155. Thirty-five of the 40 patents are assigned to DeKalb, 3 patents to Rustica Prograin Genetique and 2 to Pioneer. The correlation between claims and the number of DeKalb patents that cover the same hybrid is 0.0922.

Overall, the data suggest that claims and the structure of patents (number of patents covering the same hybrid and number of hybrids covered by the same patent) are specific to breeders, who follow their own, firm-specific templates of patent applications, and may therefore contain only limited

information regarding the scope of patents, at least for hybrid corn.

Citations are highly correlated with the magnitude of inventive output for hybrid corn

OLS and negative binomial regressions estimate the correlation between citations and the size of improvements in yields and other characteristics, using claims to control for the scope of patents and allowing for year and firm fixed effects:

$$Citations_i = \alpha_0 + \beta_1\ Increase\ in\ yields_i + \beta_2\ Claims_i + \gamma \cdot Z_i + \delta_i + DeKalb_i + Other\ firm_i + \varepsilon_i$$

where *Citations* counts the number of later patents that cite one of the 256 patents for corn hybrids, *Increase in yields* measures the percent increase in yields that the newly patented hybrid offers over existing hybrids, and *Claims* counts the number of claims that define the scope of the patent. The variable δ indicates year fixed effects, *DeKalb* distinguishes patents assigned to DeKalb, and *other firms* denotes patents that are neither assigned to DeKalb or Pioneer, which is the excluded category.. The coefficient β_1 measures the conditional correlation between increases in yields and counts of citations. Firm fixed effects use the firm with the largest number of patents, which is Pioneer, as the baseline. 129 out of the 256 patents (30 percent) in our data are assigned to Pioneer.

Comparisons between citations counts and increases in yields indicate a strong positive correlation (Figure 12). OLS and negative binomial regressions with additional controls for the number of claims of a patent, the number of hybrids covered by the patent, the number of other patents covering a hybrid, year of application, firm and/or year fixed effects, confirm these results (Table 7).[31]

[31] We estimate negative binomial regressions instead of Poisson to account for over-dispersion in the dependent variable. If two regressors in a count data model are collinear for the subsample of positive observations of the dependent variable, maximum-likelihood estimates may yield spurious estimates (Santos-Silva and Tenreyro 2009). We checked whether any pair of regressors in the subsample of observations with a strictly positive number of citations are collinear, and found no evidence of collinearity. Out of 110 patents assigned to DeKalb, 102 patents also cover the hybrid's parent inbred in addition to the new hybrid. In addition to the reported regressions, we run the specification reported in column (3) and (4) with an additional dummy variable controlling for whether or not a parent inbred is also covered. Neither the coefficients on the percentage increase in yield (up to 3 digits of precision) nor the significance levels are changed due to

In negative binomial regressions on a restricted sample (excluding the five outlier patents) with firm- and year-fixed effects, a 10 percentage point increase in yields is associated with 1.9 additional citations (Table 8, column 1, significant at the 1 percent level), and a 10 percentage point increase in income is associated with 2.5 additional citations (Table 10, column 1, significant at the 1 percent level) when the comparison is made with respect to the highest-yielding comparison hybrid. A 10 percentage point increase in yields is associated with 2.4 additional citations when the comparison is made with respect to the average comparison hybrid (Table 9, column 1, significant at the 1 percent level). These results are robust to alternative specifications as OLS (Tables 8 to 10 column 5, significant at the 1 percent level), as well as the inclusion of linear and quadratic time trends (Tables 8 to 10, columns 2 and 6, significant at the 1 percent level). Considering direct and indirect comparisons separately, the coefficient on percentage increases in yield or income is consistently positive and significant (Table 11).

Coefficient estimates for the number of claims are not significant at the 10 percent level in any specification (Table 7 to 11). In addition to the number of claims, which is a measure of the scope of a patent, we also uses the number of hybrids covered by the patent as well as the number of other hybrids covering the patented hybrid as alternative measures for the scope of a patent. Both variables are not significant the 10 percent level (Table 7 to 10, columns (3) and (7)). Since Pioneer patents do not show any variation in the number of hybrids covered (always equal to 1) or the number of other patents covering the same hybrid (always equal to zero), we ran the same regressions for a subset of our dataset, including only patents assigned to DeKalb. The coefficient on the percentage increase in yield or income remains positive and significant, but becomes larger (Table 8 to 10, columns (4) and (8)).

Estimates in the dataset including the outlier patents are substantially larger, implying between 4 and 6 additional citations (Table 7, Full sample).

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the inclusion of the extra dummy variable.

Other characteristics: Suitability to different climates

The most important limitation of our tests is that, although we use data on yields as the bottom line measure of most characteristics and include moisture as an additional control, we cannot control for all characteristics of hybrid corn. Most of these characteristics, such as resistance to herbicides or pests, affect the quality of hybrid corn through improvements in yields, but one important adaptive characteristics – variation in the suitable to different climates -- cannot be captured by measuring yields.[32] New hybrids may have been developed to take advantage of climatic conditions in different locations of North America; regions with colder climates and shorter summers require hybrids with earlier relative maturity rates (i.e., fewer days required to grow.)

To examine whether such variation might explain relatively low rates of improvement measured by raw patent counts, or perhaps even the strong positive correlation between yields and citations, we collect data on variation in relative levels of maturity for Pioneer's hybrid, whose names include encoded information on relative maturity. Specifically, the second digit in the product names of new Pioneer hybrids between 1997 and 2005 identifies the relative maturity level on a scale from 0 (very full) to 9 (very short).[33] For example, the digit 9 preceding the "r" in the name of Pioneer's new hybrid 39r34 (USPTO 6,797,868 granted on September 28, 2004), for example, indicates that this hybrid has a very short relative maturity. 89 of 215 total hybrids between 1997 and 2005 are Pioneer hybrids, we are able to measure relative maturity for 89 hybrids of these hybrids.

Data on variation in the relative maturity of Pioneer hybrids yield no evidence of systematic changes over time (Figure A7) or, more importantly, in the number of citations (Figure 13). The

[32] Variation in the sugar content of hybrids is another important characteristic that is not captured by variation in yields; to avoid this problem, we focus on a) field corn rather than sweet corn and b) on patent grants that precede the Energy Act of 2005, which increased the relative price of ethanol and motivated breeders of field corn to shift towards improving hybrids to produce more sugar (and thereby ethanol).

[33] See www.pioneer.com/home/site/ca/products/product-naming-system for a key to Pioneer's naming practices.

correlation coefficient between the relative maturity level and the number of citations is 0.0011.[34]

CONCLUSIONS

Our analysis of 256 patent-field trial pairs for hybrid corn between 1986 and 2005 suggests that more than half of all newly patented hybrids do not produce more corn or income than existing hybrids. The data also indicate that improvements in yields per acre and in income are declining over time, possibly due to decreasing returns to invention. Importantly, however, we establish a strong and robust positive correlation between citations count and the magnitude of innovations, suggesting that citations-adjusted patent counts are a useful measure for the magnitude of biological innovations.

Our ongoing research expands this analysis to include soybeans, as well as additional data on citing patents, including the identity of inventors and firms. In future work, we plan to extend the analysis of effects in the market structure of biotechnology firms on patenting and innovation.

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TABLE 1 – SUMMARY STATISTICS

	Full sample				Excluding outliers			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Number of citations per patent	7.55	39.50	0	551	3.02	4.48	0	32
% increase in yield per acre (comparison with the highest-yielding hybrid)								
All comparisons	-1.06	5.22	-26.99	10.48	-1.14	5.22	-26.99	10.48
Direct comparisons	1.07	4.38	-16.86	12.34	1.04	4.38	-16.86	12.34
Indirect comparisons	-1.92	5.63	-26.99	9.99	-1.95	5.63	-26.99	9.99
% increase in yield per acre (comparison with the average-yielding hybrid)								
All comparisons	2.93	4.36	-11.96	16.94	2.88	4.31	-11.96	16.94
Direct comparisons	3.65	4.04	-8.40	16.94	3.62	4.00	-8.40	16.94
Indirect comparisons	1.06	5.25	-18.28	15.88	1.03	5.25	-18.28	15.88
% increase in income per acre (comparison with the highest-yielding hybrid)								
All comparisons	-0.96	5.05	-25.60	11.17	-1.03	5.05	-25.60	11.17
Direct comparisons	1.00	4.16	-16.01	11.31	0.97	4.17	-16.01	11.31
Indirect comparisons	-1.79	5.36	-25.60	11.45	-1.81	5.36	-25.60	11.45
# of claims	24.22	13.41	2	55	24.52	13.30	2	55
Year of application	12.93	2.71	0	17	13.11	2.27	4	17
# of hybrids covered by this patent	1.25	1.16	1	10	1.25	1.17	1	10
# of other patents covering this hybrid	0.20	0.51	0	2	0.21	0.51	0	2
Pioneer	0.50	0.50	0	1	0.51	0.50	0	1
DeKalb	0.43	0.50	0	1	0.43	0.50	0	1
Other firm	0.07	0.25	0	1	0.07	0.25	0	1

Notes: Five outliers have exceptionally high citation counts (136,137, 139, 212, and 551). Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 *Maize* available at www.uspto.gov. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use $2.25 per bushel of corn and drying costs of $0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. *Year of application* uses 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation.

TABLE 2 – IMPROVEMENTS IN YIELD AND INCOME PER ACRE

	Number of observations	Mean number of comparison hybrids	Share of patents that show an increase in	
			yield per acre	income per acre
All comparisons	256	5.10	41.80	44.14
Direct comparisons	256	2.84	62.89	62.89
Indirect comparisons	172	3.26	34.50	34.88

Notes: An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 *Maize* (available at www.uspto.gov). On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To be patentable, new hybrids must be novel, useful, and non-obvious. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov). Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid.

TABLE 3 – RENEWAL DECISIONS

	Number of observations	Share of patents that are renewed
4 years after the patent grant	256	98.05 %
8 years after the patent grant	224	97.32 %
12 years after the patent grant	71	92.96 %

Notes: Data include renewals up to 2010. This leads to truncation: Renewals after 12 years are observable only for patents granted up to 1998. Renewals after 8 years are observable only for patents granted up to 2002. Patent and renewal fee data from the USPTO.

TABLE 4 – AVERAGE NUMBER OF CITATIONS CONDITIONAL ON DECISION TO RENEW THE PATENT

	Renewal after 4 years		Renewal after 8 years		Renewal after 12 years	
	Yes	No	Yes	No	Yes	No
Full sample	7.47	9.50	8.22	7.60	14.95	43.75
Excluding USPTO patents 4,607,453; 4,629,819; 4,731,499; 4,737,596; 6,433,261	2.85	9.50	2.90	7.60	2.56	12.67

Notes: Data include all patent renewals up to October 2010. Renewals after 8 and 12 years are observable for patents granted up to October 2002 and October 1998, respectively. Data on patents, renewal decisions and citations were collected from www.uspto.gov. USPTO patent 4,607,453 (for DeKalb hybrid DK672, granted in August 1986) and patent 4,629,819 (for DeKalb hybrid DK524, granted in December 1986) are cited 136 times and 137 times respectively. USPTO patents 4,731,499 (for Pioneer hybrid 3790, granted in March 1988) and 4,737,596 (for Pioneer hybrid 3471, granted in April 1988) are cited 551 and 139 times respectively. USPTO patent 6,433,261 (for DeKalb hybrid 8012685, granted in August 2002) is cited 212 times.

TABLE 5 – IMPROVEMENTS IN YIELD AND INCOME PER ACRE BY PATENT EXAMINER

Patent examiner	Number of observations	Average percentage increase in yield per acre	income per acre
Examiner A	189	-1.24	-1.25
Examiner B	34	-1.57	-1.12
Examiner C	19	-0.12	0.52
Examiner D	5	1.10	1.92
Examiner E	4	2.90	2.88
Examiner F	2	1.51	0.74
Examiner G	1	-0.90	-1.72
Examiner H	1	-4.06	-4.28
Examiner I	1	3.23	1.92
Weighted average	-	-1.06	-0.96

Notes: An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 *Maize* (available at www.uspto.gov). Information on the primary patent examiner was obtained through an automated search. On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov).

TABLE 6 – IMPROVEMENTS IN YIELD AND INCOME PER ACRE BY ASSIGNEE

Name of assignee	Number of observations	Average percentage increase in yield per acre	income per acre
Pioneer	129	-2.40	-2.22
Dekalb Genetics [1)]	110	0.33	-0.07
Asgrow [1)]	8	-1.34	-0.13
Rustica Prograin Genetique	3	-2.90	0.18
Kleinwnzlebener Saatzucht	2	2.75	1.56
Monsanto [1)]	2	1.48	0.65
Euralis	1	9.93	10.30
Sandoz	1	3.33	7.30
Weighted average	-	-1.06	-1.06

Notes: 1) Monsanto acquired Asgrow in 1997 and Dekalb Genetics in 1998. An observation consists of a utility patent protecting a new hybrid. Data on yields were collected by a search of patents in subclass 800/320.1 *Maize* (available at www.uspto.gov). Information on the assignee was obtained through an automated search. On the patent document breeders compare their new hybrid to existing hybrids to demonstrate that the new hybrid is a patentable improvement. To control for improvements in addition to yields, measures of income per acre incorporate information on the moisture content of hybrids. To calculate income, we assume a price of $2.25 per bushel of corn and a drying cost of $0.04 per percentage point moisture above 15% (based on price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov).

TABLE 7 – CITATIONS AS A FUNCTION OF YIELDS PER ACRE, FULL SAMPLE, DEPENDENT VARIABLE IS CITATIONS PER PATENT

	Full sample			DeKalb only	Full sample			DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.521***	0.559**	0.518***	1.067**	0.491**	0.485	0.442***	0.690*
	(0.172)	(0.285)	(0.159)	(0.452)	(0.197)	(0.309)	(0.165)	(0.404)
# of claims	-0.004	-0.013			-0.166	0.524		
	(0.114)	(0.113)			(0.153)	(0.368)		
# of hybrids covered by this patent			-0.104	-1.390			-0.386	-0.581*
			(0.628)	(1.033)			(0.312)	(0.305)
# of other patents covering this hybrid			1.649	1.964			0.552	0.314
			(1.520)	(2.200)			(0.898)	(1.284)
Year of application		-0.841**				-34.522**		
		(0.368)				(13.543)		
Year of application ²						1.327**		
						(0.495)		
DeKalb	1.461	2.547	0.780		4.319	-12.201	1.853	
	(2.233)	(3.058)	(1.677)		(4.237)	(10.652)	(2.478)	
Other firm	-11.764***	-3.909*	-13.077***		-3.646*	-18.890**	-5.517**	
	(4.222)	(2.258)	(4.671)		(1.922)	(8.017)	(2.582)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-578.951	-627.712	-578.380	-283.135	-1159.751	-1239.276	-1160.022	-484.713
Pseudo R^2	0.145	0.073	0.146	0.101				
R^2					0.676	0.396	0.675	0.458
N	256	256	256	110	256	256	256	110

Average marginal effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

TABLE 8 – CITATIONS AS A FUNCTION OF YIELDS PER ACRE, DEPENDENT VARIABLE IS CITATIONS PER PATENT EXCLUDING FOUNDATIONAL PATENTS 4,607,453; 4,629,819; 4,731,499; 4,737,596; AND 6,433,261

		Full sample		DeKalb only		Full sample		DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.191***	0.187***	0.207***	0.373***	0.195***	0.182***	0.212***	0.322***
	(0.061)	(0.056)	(0.059)	(0.121)	(0.057)	(0.052)	(0.056)	(0.118)
# of claims	0.041	0.022			0.037	0.035		
	(0.042)	(0.032)			(0.038)	(0.034)		
# of hybrids covered by this patent			-0.085	-0.586			-0.211	-0.489*
			(0.229)	(0.434)			(0.188)	(0.298)
# of other patents covering this hybrid			0.857	1.198			0.978	1.073
			(0.605)	(0.933)			(0.652)	(0.955)
Year of application		0.053				-1.030		
		(0.138)				(0.798)		
Year of application^2						0.043		
						(0.032)		
DeKalb	-0.529	0.337	-0.233		-0.307	0.255	-0.011	
	(0.697)	(0.658)	(0.589)		(0.759)	(0.768)	(0.649)	
Other firm	-3.744***	-2.748***	-3.794***		-2.958***	-2.567***	-3.018***	
	(1.127)	(0.965)	(1.104)		(0.741)	(0.679)	(0.786)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-530.536	-543.046	-529.984	-250.339	-704.102	-719.916	-703.351	-327.747
Pseudo R^2	0.047	0.025	0.048	0.045				
R^2					0.195	0.086	0.199	0.135
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

TABLE 9 – CITATIONS AS A FUNCTION OF YIELDS PER ACRE, COMPARISON WITH THE AVERAGE-YIELDING HYBRID, DEPENDENT VARIABLE IS CITATIONS PER PATENT, EXCLUDING FOUNDATIONAL PATENTS 4,607,453; 4,629,819; 4,731,499; 4,737,596; AND 6,433,261

	Full sample			DeKalb only	Full sample			DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in yield per acre	0.239***	0.232***	0.258***	0.398***	0.225***	0.208***	0.244***	0.339***
	(0.059)	(0.058)	(0.061)	(0.127)	(0.056)	(0.054)	(0.055)	(0.114)
# of claims	0.043	0.025			0.039	0.033		
	(0.042)	(0.033)			(0.039)	(0.035)		
# of hybrids covered by this patent			-0.169	-0.810*			-0.254	-0.636**
			(0.247)	(0.457)			(0.192)	(0.289)
# of other patents covering this hybrid			0.802	1.367			0.865	1.235
			(0.652)	(0.981)			(0.665)	(0.971)
Year of application		0.020				-0.972		
		(0.146)				(0.831)		
Year of application ²						0.040		
						(0.033)		
DeKalb	-0.195	0.730	0.217		0.020	0.636	0.431	
	(0.720)	(0.693)	(0.617)		(0.784)	(0.806)	(0.673)	
Other firm	-3.928***	-2.742**	-3.843***		-3.148***	-2.592***	-3.077***	
	(1.136)	(0.993)	(1.142)		(0.762)	(0.711)	(0.822)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-529.554	-543.042	-529.251	-251.158	-704.053	-720.298	-703.538	-328.262
Pseudo R^2	0.049	0.025	0.049	0.041				
R^2					0.195	0.084	0.198	0.127
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.10$

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

TABLE 10 – CITATIONS AS A FUNCTION OF INCOME PER ACRE, DEPENDENT VARIABLE IS CITATIONS PER PATENT EXCLUDING FOUNDATIONAL PATENTS 4,607,453; 4,629,819; 4,731,499; 4,737,596; AND 6,433,261

	Full sample			DeKalb only	Full sample			DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in income per acre	0.253***	0.220***	0.260***	0.379***	0.244***	0.218***	0.254***	0.326***
	(0.071)	(0.061)	(0.065)	(0.118)	(0.063)	(0.059)	(0.061)	(0.118)
# of claims	0.013	0.009			0.018	0.024		
	(0.042)	(0.031)			(0.038)	(0.034)		
# of hybrids covered by this patent			-0.092	-0.637			-0.192	-0.491*
			(0.230)	(0.422)			(0.188)	(0.285)
# of other patents covering this hybrid			0.928	1.385			0.929	1.086
			(0.581)	(0.917)			(0.653)	(0.959)
Year of application		0.104				-0.922		
		(0.135)				(0.786)		
Year of application ^{2}						0.040		
						(0.032)		
DeKalb	-0.151	0.620	-0.295		-0.020	0.445	0.002	
	(0.695)	(0.672)	(0.552)		(0.771)	(0.779)	(0.634)	
Other firm	-3.707***	-2.894***	-4.150***		-3.089***	-2.825***	-3.362***	
	(1.094)	(0.981)	(1.105)		(0.752)	(0.708)	(0.799)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-526.380	-540.803	-525.089	-249.480	-701.245	-717.990	-700.210	-327.439
Pseudo R^2	0.055	0.029	0.057	0.048				
R^2					0.213	0.100	0.219	0.140
N	251	251	251	107	251	251	251	107

Average marginal effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use $2.25 per bushel of corn and drying costs of $0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

TABLE 11 – CITATIONS AS A FUNCTION OF YIELDS PER ACRE, DIRECT AND INDIRECT COMPARISONS, DEPENDENT VARIABLE IS CITATIONS PER PATENT, EXCLUDING FOUNDATIONAL PATENTS 4,607,453; 4,629,819; 4,731,499; 4,737,596; AND 6,433,261

	Direct comparisons				Indirect comparisons			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS
% increase in yield per acre	0.189***	0.167***	0.183***	0.156***	0.098**	0.116**	0.092*	0.118*
	(0.060)	(0.059)	(0.060)	(0.055)	(0.049)	(0.048)	(0.047)	(0.062)
# of claims	-0.045	-0.018		-0.021	-0.026	-0.011		-0.014
	(0.040)	(0.031)		(0.029)	(0.041)	(0.030)		(0.031)
# of hybrids covered by this patent			-0.343				-0.129	
			(0.294)				(0.281)	
# of other patents covering this hybrid			0.842*				0.769	
			(0.512)				(0.520)	
Year of application		0.191				0.212		
		(0.149)				(0.144)		
DeKalb	0.012	0.544	-0.656	-0.036	0.034	0.568	-0.535	0.061
	(0.667)	(0.693)	(0.533)	(0.827)	(0.707)	(0.652)	(0.534)	(0.857)
Other firm	-2.727***	-2.137**	-3.682***	-2.534***	-2.359**	-1.729**	-3.200***	-2.359**
	(1.005)	(0.882)	(1.118)	(0.907)	(1.028)	(0.840)	(1.070)	(0.952)
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-329.355	-344.170	-329.051	-430.599	-331.905	-344.124	-331.432	-430.997
Pseudo R^2	0.060	0.018	0.061		0.053	0.018	0.054	
R^2				0.287				0.283
N	170	170	170	170	170	170	170	170

Average marginal effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

TABLE 12 – COMPARING CITATIONS FOR HYBRIDS AND INBREDS

	Full sample				Excluding outliers			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Patents for hybrids (*N*=256)								
Number of citations per patent	7.55	39.50	0	551	3.02	4.48	0	32
Patents for inbreds (*N*=488)								
Number of citations per patent	11.28	54.26	0	574	4.37	8.02	0	72

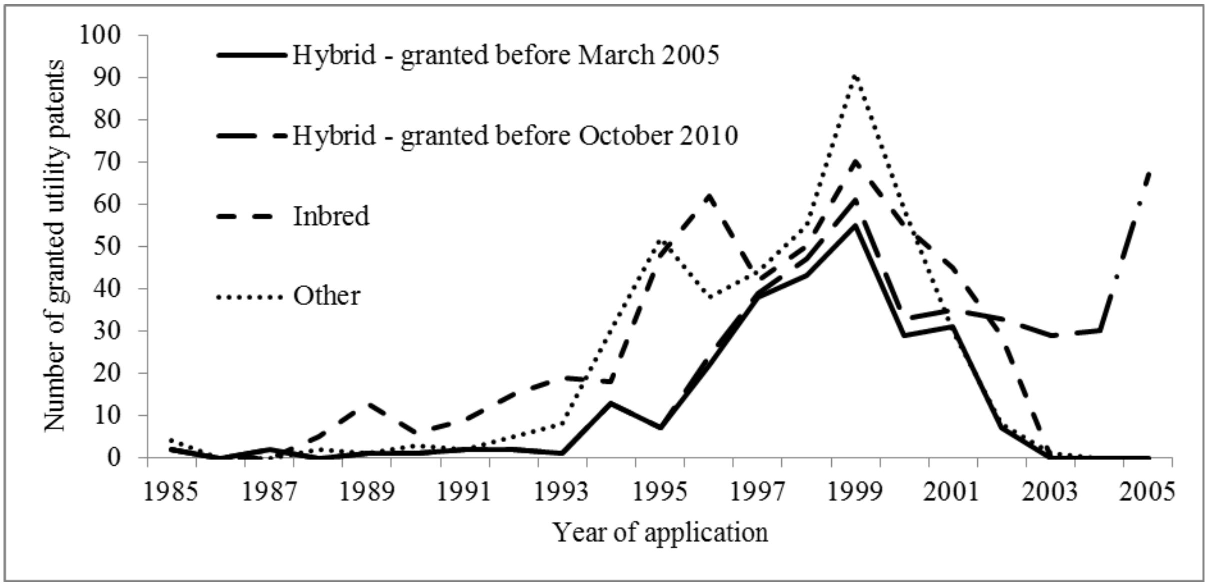
Notes: Five outlier patents for hybrids have exceptionally high (forward) citation counts with more than 100 citations. There are 11 outlier patent for inbreds. Data on citations were collected from the USPTO's Patent Full-Text database available at www.uspto.gov.

TABLE 13 – CITATIONS FOR HYBRIDS AND INBREDS BY TYPE OF CITING PATENT

	Full sample			Excluding outliers		
	Hybrids	Inbreds	Other	Hybrids	Inbreds	Others
Patents for hybrids						
Share of citations received from	83.3%	7.9%	8.8%	53.2%	17.9%	29.5%
Patents for inbreds						
Share of citations received from	40.6%	48.9%	10.4%	15.6%	71.2%	13.2%

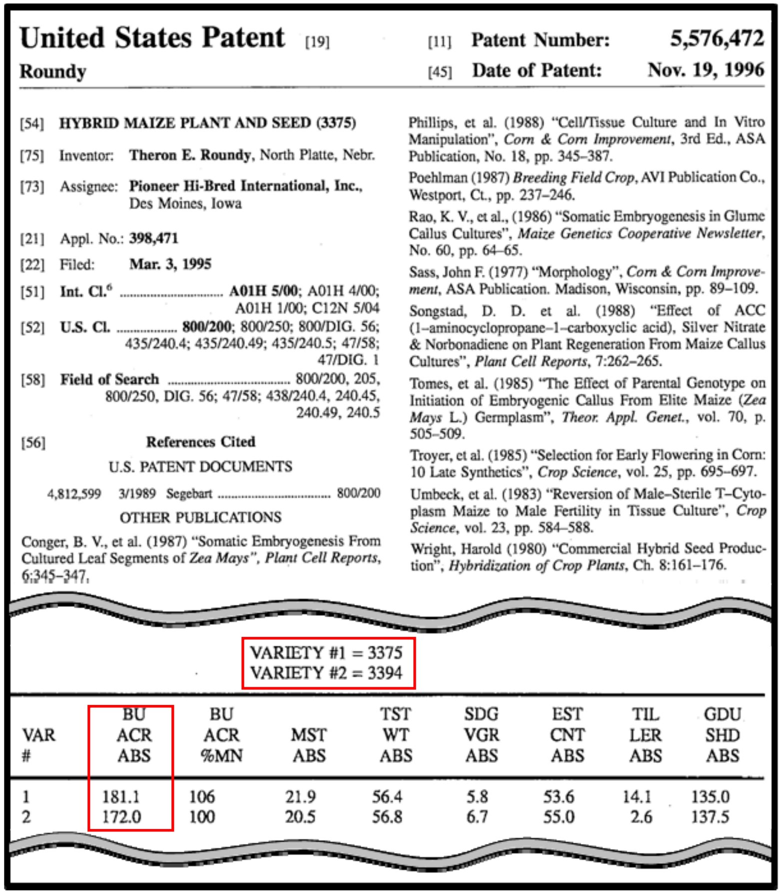
Notes: Five outlier patents for hybrids have exceptionally high (forward) citation counts with more than 100 citations. There are 11 outlier patent for inbreds. Analysis based on all citations made before October 2005. We observe whether a citing patent protects a hybrid, an inbred or another type of invention only for patents granted before October 2005. Data on citations were collected from the USPTO's Patent Full-Text database available at www.uspto.gov

FIGURE 1 – UTILITY PATENTS IN SUBCLASS 800/320.1 *MAIZE* BY YEAR OF APPLICATION



Notes: Data include all 1,181 patents that were granted in subclass 800/320.1 *Maize* (available at www.uspto.gov) between January 1, 1985 and March 8, 2005. 256 patents are granted for hybrid corn. Some breeders stop to record comparable data for hybrid corn after March 8, 2005. For corn hybrids, the figure also shows all patents granted up to October 31, 2010 (when the data was collected).

FIGURE 2 – TWO EXAMPLES OF PATENTS FOR HYBRID CORN



United States Patent [19] [11] **Patent Number: 5,576,472**

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

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

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

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

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

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

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

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

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

[56] **References Cited**

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4,812,599 3/1989 Segebart 800/200

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Poehlman (1987) *Breeding Field Crop*, AVI Publication Co., Westport, Ct., pp. 237–246.

Rao, K. V., et al., (1986) "Somatic Embryogenesis in Glume Callus Cultures", *Maize Genetics Cooperative Newsletter*, No. 60, pp. 64–65.

Sass, John F. (1977) "Morphology", *Corn & Corn Improvement*, ASA Publication. Madison, Wisconsin, pp. 89–109.

Songstad, D. D. et al. (1988) "Effect of ACC (1–aminocyclopropane–1–carboxyclic acid), Silver Nitrate & Norbonadiene on Plant Regeneration From Maize Callus Cultures", *Plant Cell Reports*, 7:262–265.

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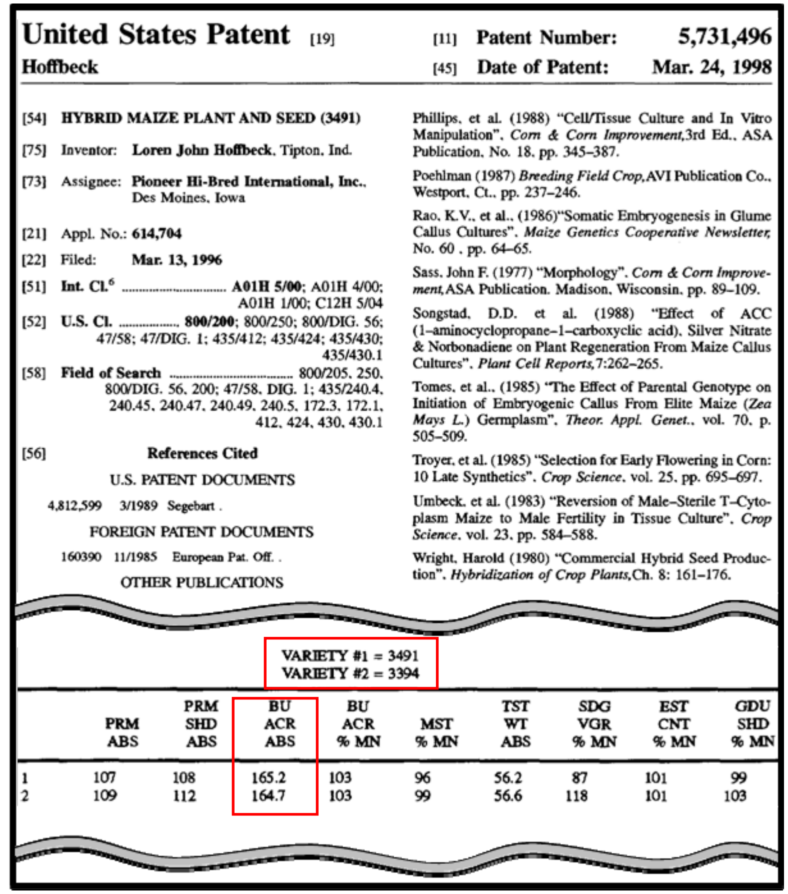
Troyer, et al. (1985) "Selection for Early Flowering in Corn: 10 Late Synthetics", *Crop Science*, vol. 25, pp. 695–697.

Umbeck, et al. (1983) "Reversion of Male–Sterile T–Cytoplasm Maize to Male Fertility in Tissue Culture", *Crop Science*, vol. 23, pp. 584–588.

Wright, Harold (1980) "Commercial Hybrid Seed Production", *Hybridization of Crop Plants*, Ch. 8:161–176.

VARIETY #1 = 3375
VARIETY #2 = 3394

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



United States Patent [19] [11] **Patent Number: 5,731,496**

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

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

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

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

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

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

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

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

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

[56] **References Cited**

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4,812,599 3/1989 Segebart .

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Poehlman (1987) *Breeding Field Crop*, AVI Publication Co., Westport, Ct., pp. 237–246.

Rao, K.V., et al., (1986) "Somatic Embryogenesis in Glume Callus Cultures", *Maize Genetics Cooperative Newsletter*, No. 60 , pp. 64–65.

Sass, John F. (1977) "Morphology", *Corn & Corn Improvement*, ASA Publication, Madison, Wisconsin, pp. 89–109.

Songstad, D.D. et al. (1988) "Effect of ACC (1–aminocyclopropane–1–carboxyclic acid), Silver Nitrate & Norbonadiene on Plant Regeneration From Maize Callus Cultures", *Plant Cell Reports*, 7:262–265.

Tomes, et al., (1985) "The Effect of Parental Genotype on Initiation of Embryogenic Callus From Elite Maize (*Zea Mays L.*) Germplasm", *Theor. Appl. Genet.*, vol. 70, p. 505–509.

Troyer, et al. (1985) "Selection for Early Flowering in Corn: 10 Late Synthetics", *Crop Science*, vol. 25, pp. 695–697.

Umbeck, et al. (1983) "Reversion of Male–Sterile T–Cytoplasm Maize to Male Fertility in Tissue Culture", *Crop Science*, vol. 23, pp. 584–588.

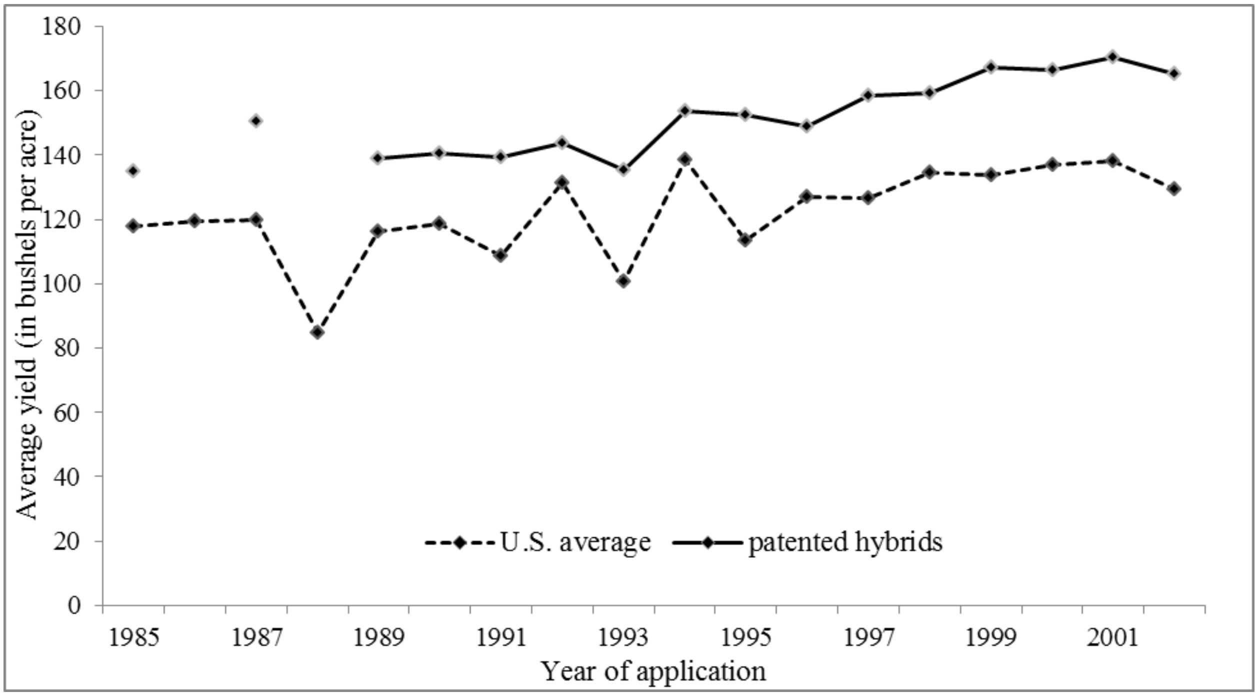
Wright, Harold (1980) "Commercial Hybrid Seed Production", *Hybridization of Crop Plants*, Ch. 8: 161–176.

VARIETY #1 = 3491
VARIETY #2 = 3394

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

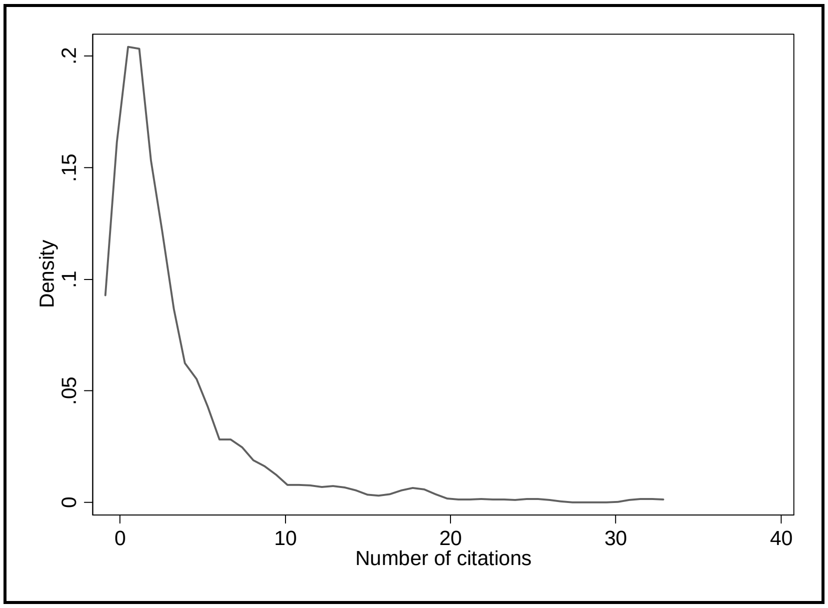
Notes: Example of 2 out of the 256 patents granted for new hybrids in subclass 800/320.1 *Maize* between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Included in the patent document are pair-wise comparisons between the newly patented hybrid and an earlier, already established, hybrid. The comparisons include information about the yield of these two hybrids (measured in bushels per acre (in absolute terms) – abbreviated as BU ACR ABS).

FIGURE 3 – YIELDS LISTED ON PATENT COMPARED WITH U.S. AVERAGES



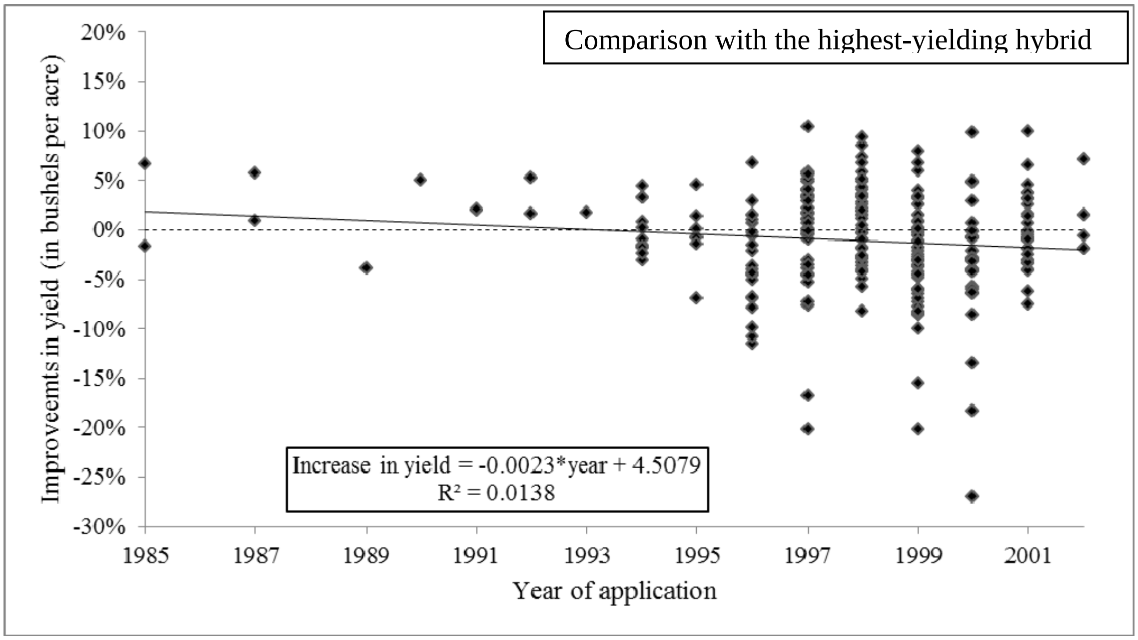
Notes: Average yields per year of application for 256 patents granted for new hybrids in subclass 800/320.1 *Maize* (available at www.uspto.gov). Yields are normalized to 15.5 percent moisture at harvest. Data on yields were collected by a manual search of the full text of patent documents. Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

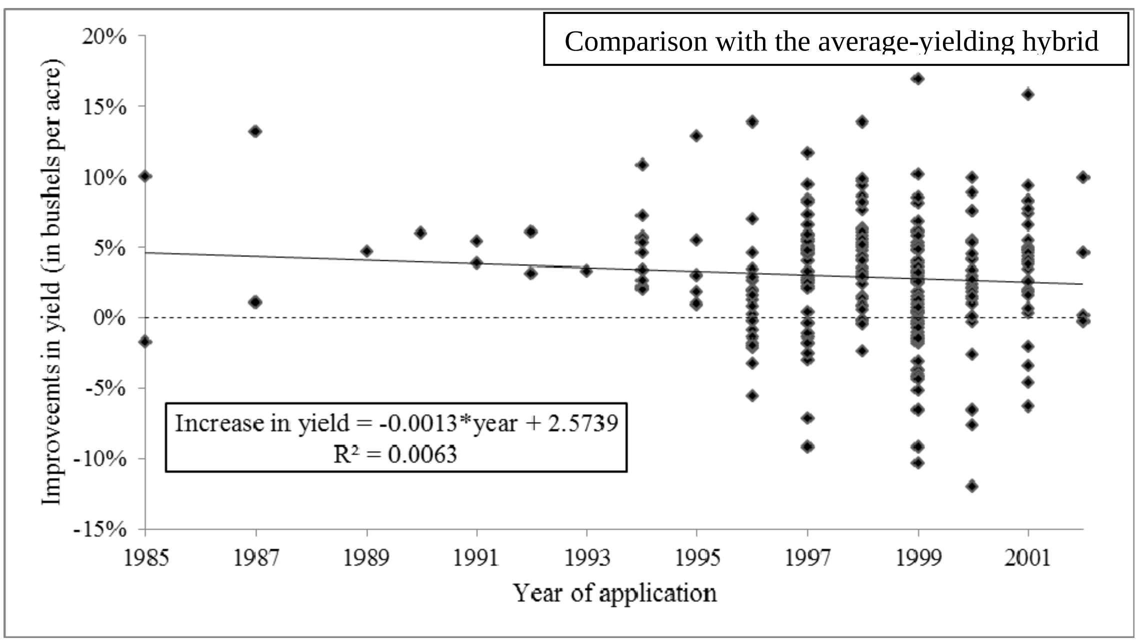
FIGURE 4 – CITATIONS PER PATENT, EXCLUDING OUTLIERS



Notes: Data on 251 patents granted for new hybrids in subclass 800/320.1 *Maize* between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Data on citations were collected by an automatic search utilizing data available at www.uspto.gov.

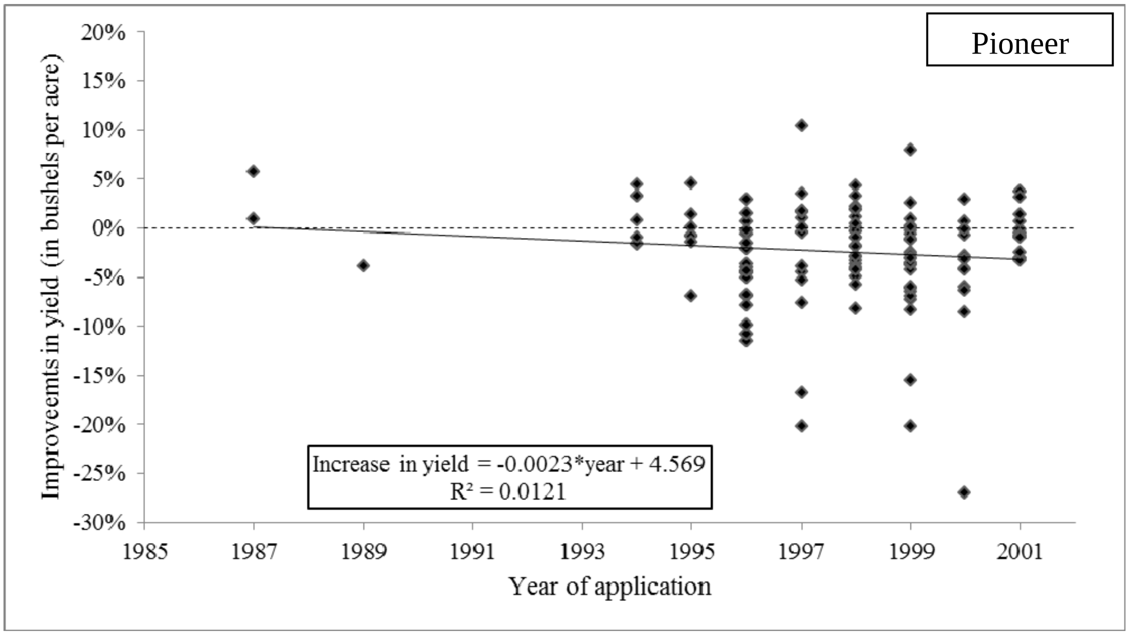
FIGURE 5 – IMPROVEMENTS IN YIELDS LISTED ON NEW PATENTS BY YEAR OF APPLICATION

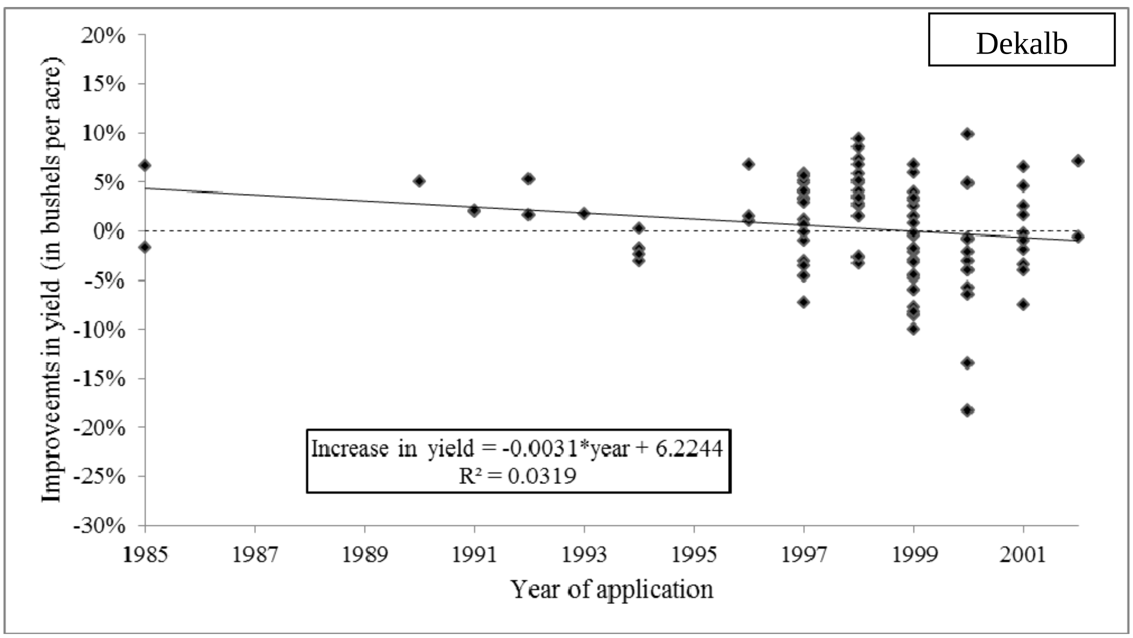




Notes: Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding (top figure) or average-yielding hybrid (bottom figure) with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Data on all 256 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov).

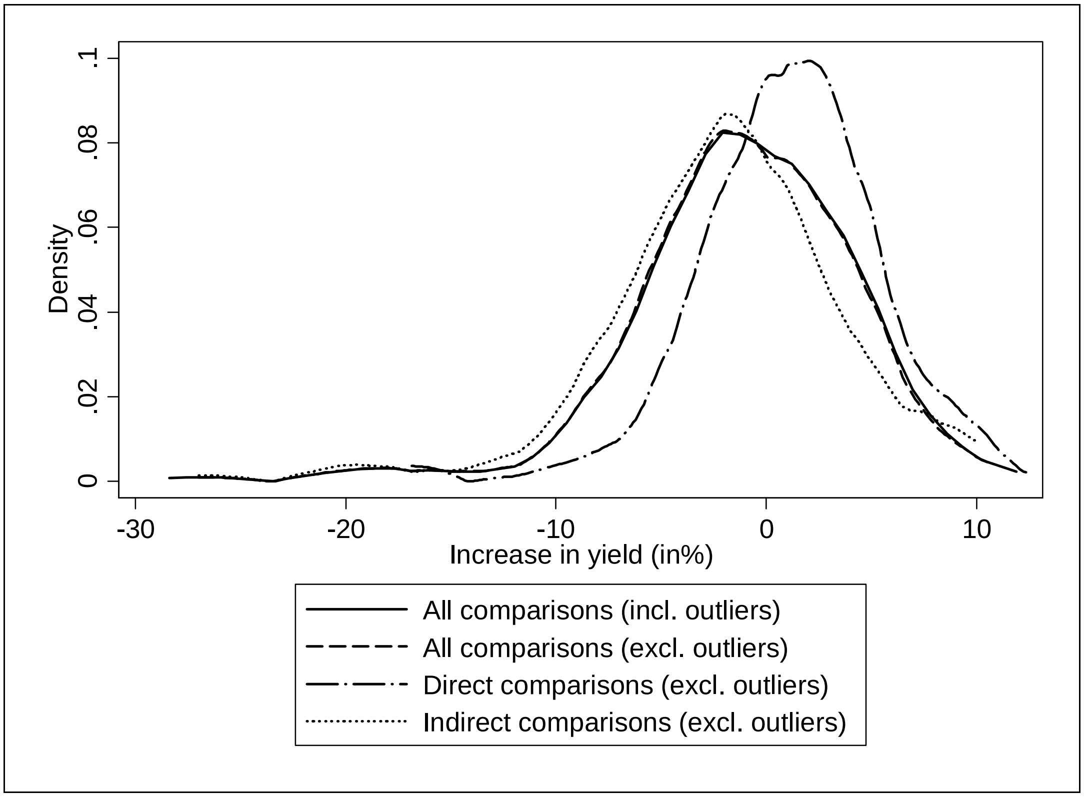
FIGURE 6 – IMPROVEMENTS IN YIELDS – PIONEER AND DEKALB





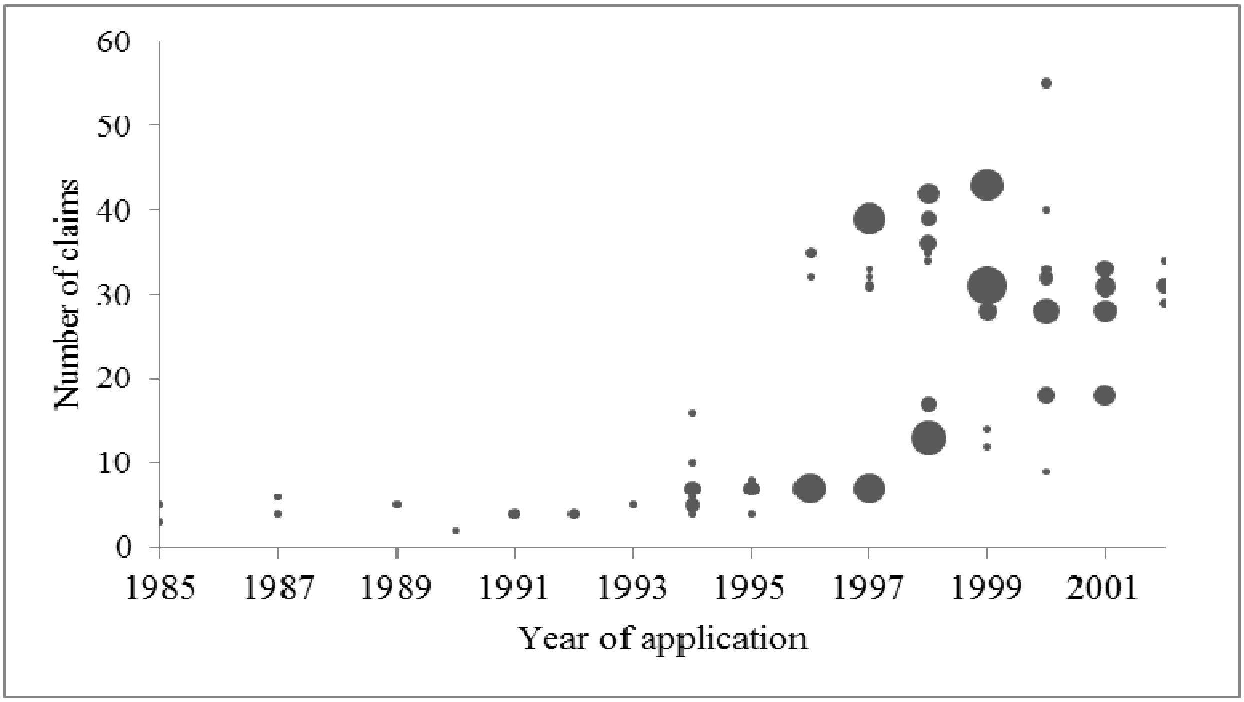
Notes: Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Data on all 129 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 assigned to Pioneer and all 110 patents assigned to Dekalb Genetics (available at www.uspto.gov).

FIGURE 7 – INCREASE IN YIELD PER ACRE



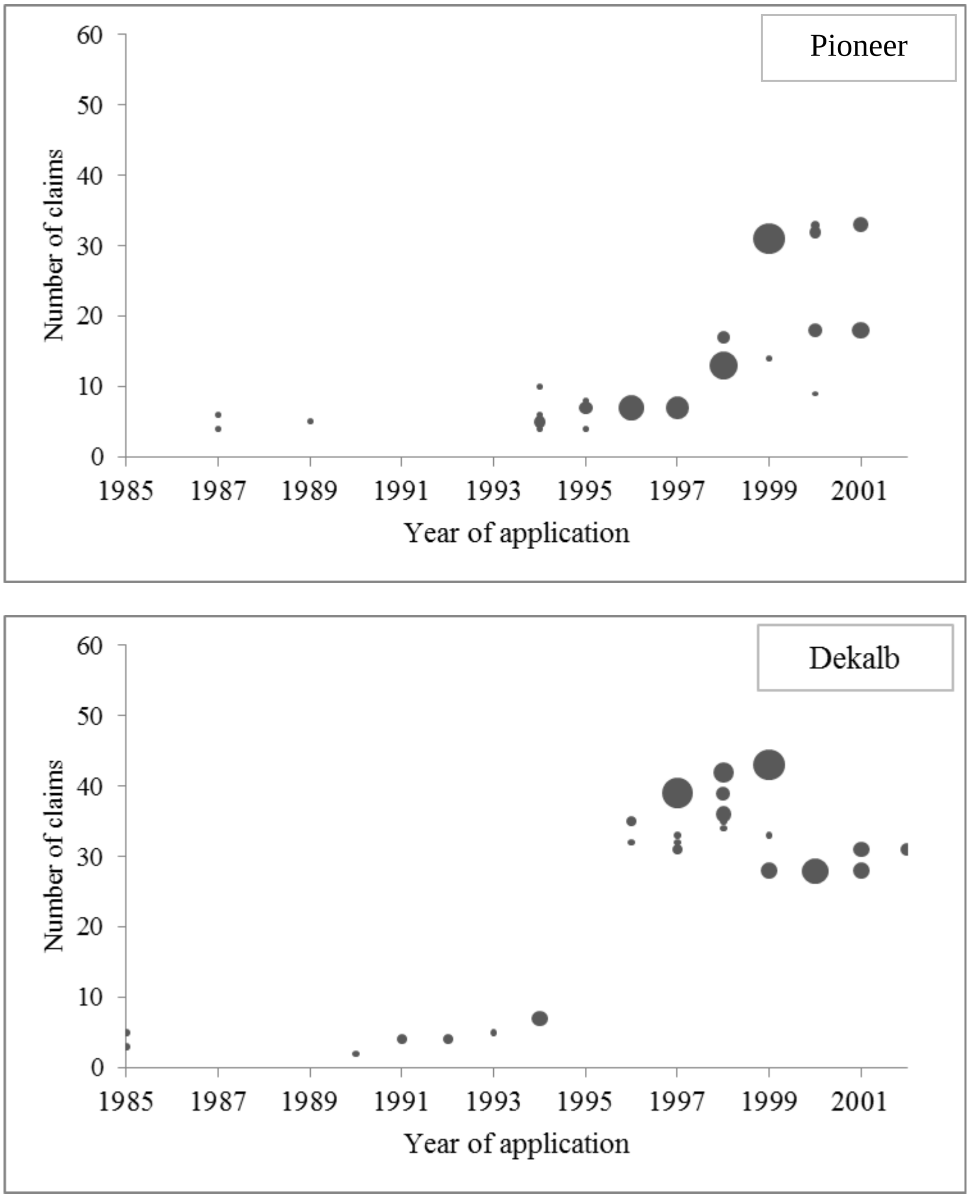
Notes: Data on 256 patents granted for new hybrids in subclass 800/320.1 *Maize* between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively.

FIGURE 8 – NUMBER OF CLAIMS BY YEAR OF APPLICATION



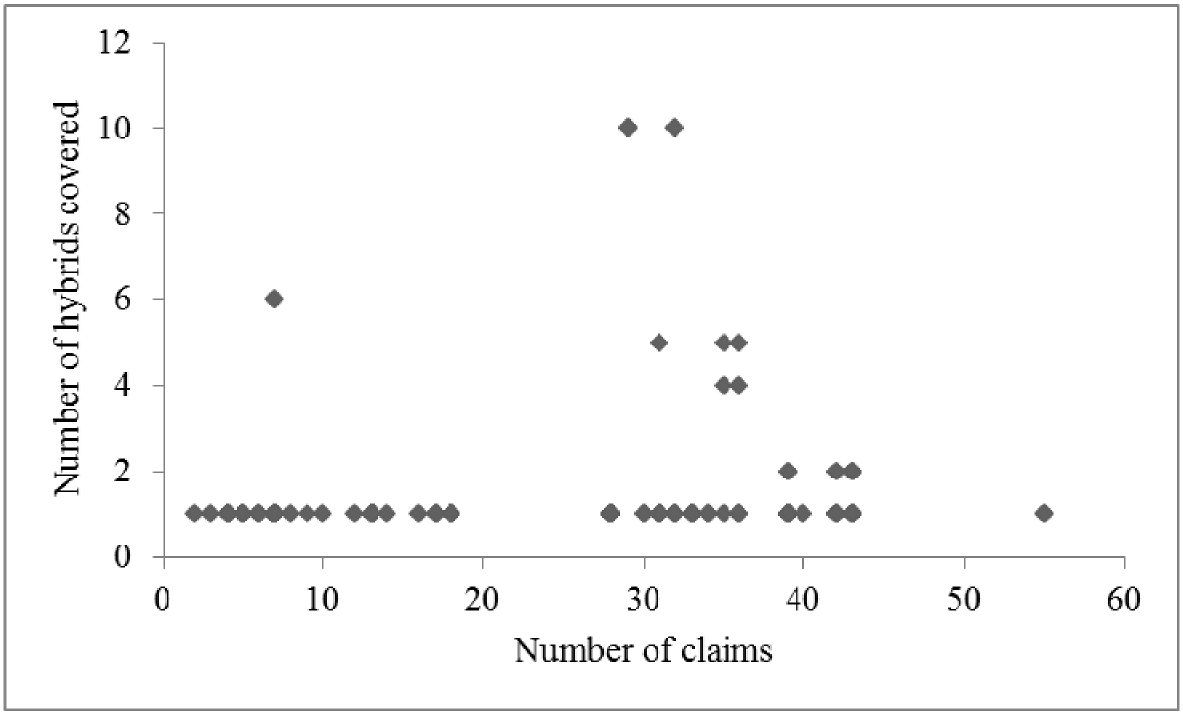
Notes: Bubble size represents the number of observations ranging from 1 to 25. For example: there are 25 patents each having 31 claims in 1999. Data on all 256 patents granted for new hybrids in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

FIGURE 9 – NUMBER OF CLAIMS BY YEAR OF APPLICATION – PIONEER AND DEKALB



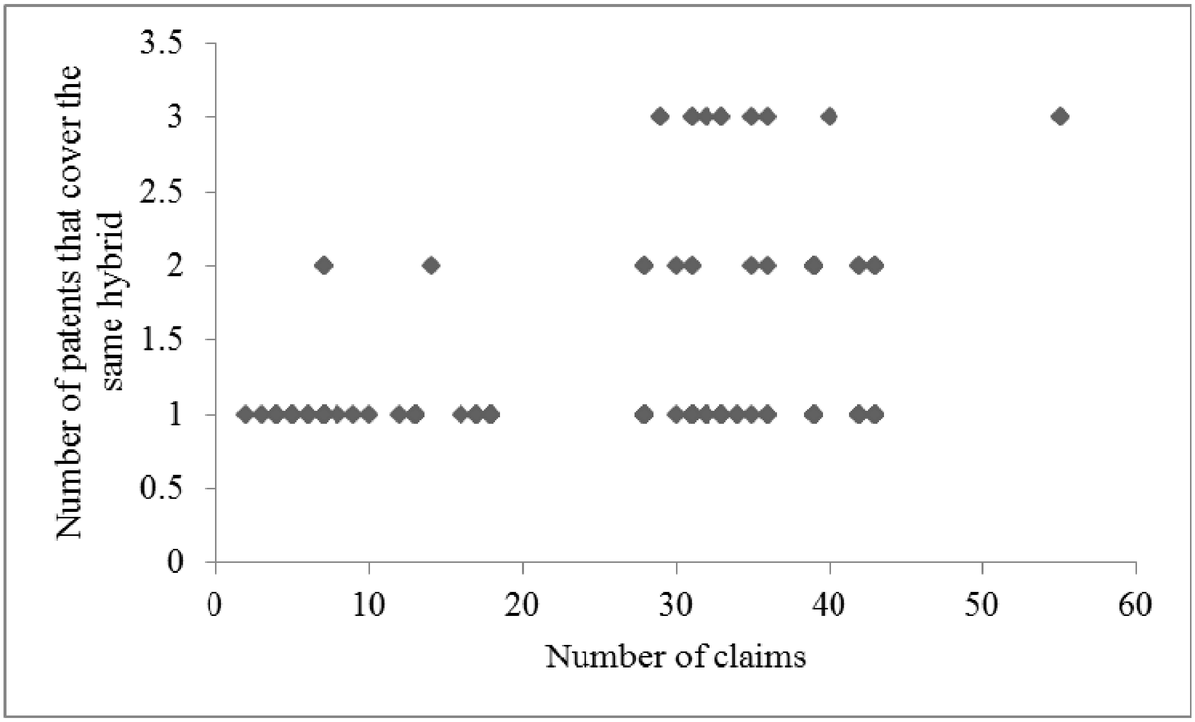
Notes: Bubble size represents the number of observations ranging from 1 to 25. For example: there are 25 patents by Pioneer each having 31 claims in 1999. Data on all 129 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 assigned to Pioneer and all 110 patents assigned to Dekalb Genetics (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

FIGURE 10 – NUMBER OF HYBRIDS COVERED VERSUS NUMBER OF CLAIMS



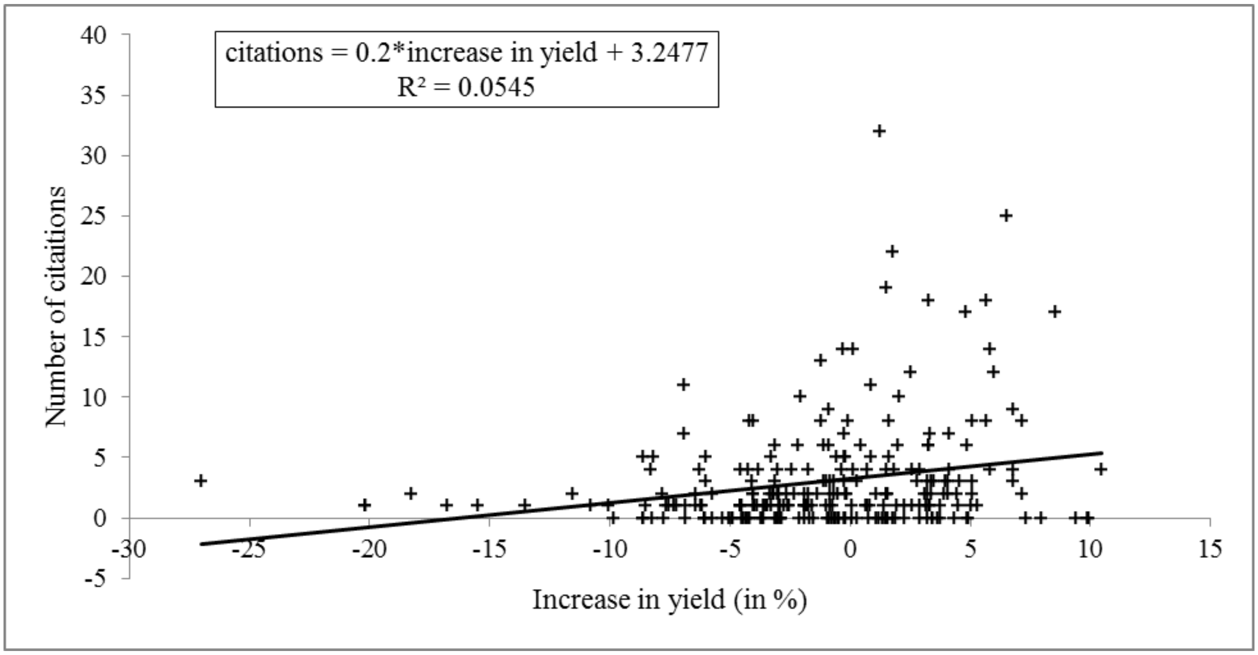
Notes: Data on all 256 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

FIGURE 11 – NUMBER OF PATENTS THAT COVER THE SAME HYBRID VERSUS NUMBER OF CLAIMS



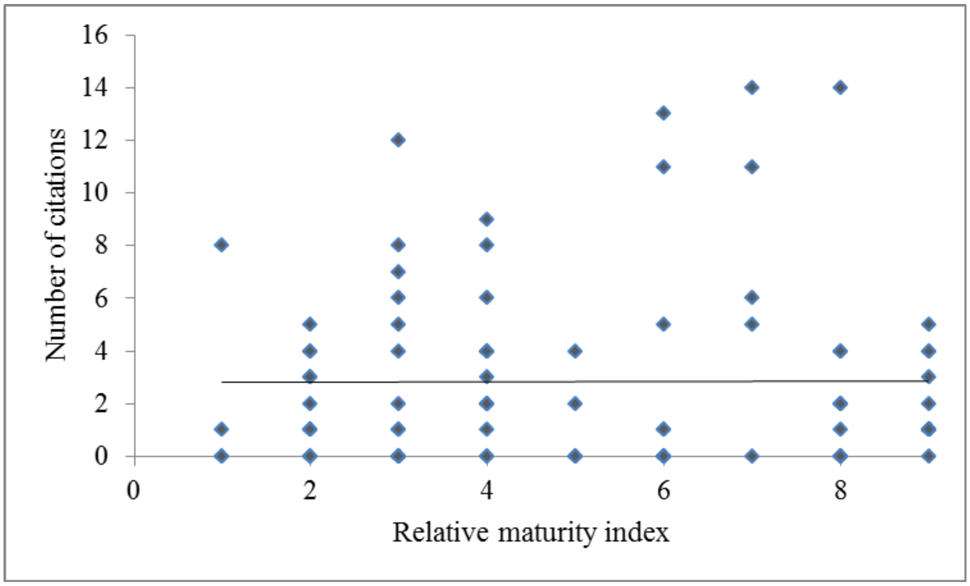
Notes: Data on all 256 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Data on claims were collected by a manual search of the full text of patent documents.

FIGURE 12 – INCREASE IN YIELD PER ACRE VERSUS NUMBER OF CITATIONS, EXCLUDING OUTLIERS



Notes: Data on 256 patents granted for new hybrids in subclass 800/320.1 *Maize* between January 1, 1985 and March 8, 2005 (available at www.uspto.gov). Improvements in yields are calculated by comparing the yield of the new hybrid with the highest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Excluding five patents that received 136, 137, 139, 212 and 551 citations respectively. Data on citations were collected by an automatic search utilizing data available at www.uspto.gov.

FIGURE 13 – RELATIVE MATURITY OF NEW PIONEER HYBRIDS VERSUS NUMBER OF CITATIONS



Notes: Starting in 1997, Pioneer reveals the relative maturity of newly patented hybrids through the product code that they assign to their new hybrids (details on the assignment of product name available at www.pioneer.com/home/site/ca/products/product-naming-system). The second digit reveals the relative maturity level with a larger number implying a shorter relative maturity. Data on all 89 patents with information on the relative maturity index in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 assigned to Pioneer (available at www.uspto.gov).

TABLE A-1 – CITATIONS AS A FUNCTION OF INCOME PER ACRE, FULL SAMPLE, DEPENDENT VARIABLE IS CITATIONS PER PATENT

	Full sample			DeKalb only	Full sample			DeKalb only
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	OLS	OLS	OLS
% increase in income per acre	0.702***	0.635*	0.658***	1.102**	0.618**	0.556	0.525***	0.675*
	(0.217)	(0.328)	(0.180)	(0.469)	(0.244)	(0.353)	(0.192)	(0.381)
# of claims	-0.083	-0.039			-0.215	0.501		
	(0.122)	(0.120)			(0.166)	(0.361)		
# of hybrids covered by this patent			-0.112	-1.551			-0.345	-0.572**
			(0.642)	(1.043)			(0.321)	(0.270)
# of other patents covering this hybrid			1.819	2.448			0.450	0.347
			(1.457)	(2.187)			(0.905)	(1.237)
Year of application		-0.775*				-34.472**		
		(0.356)				(13.495)		
Year of application ²						1.329***		
						(0.495)		
DeKalb	2.563	3.208	0.642		5.030	-11.733	1.889	
	(2.368)	(3.257)	(1.587)		(4.383)	(10.504)	(2.500)	
Other firm	-11.564***	-4.251*	-14.090***		-3.979**	-19.560**	-6.220**	
	(3.959)	(2.395)	(4.747)		(1.932)	(8.383)	(2.658)	
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-574.506	-625.677	-574.114	-282.354	-1159.147	-1239.093	-1159.617	-484.712
Pseudo R^2	0.151	0.076	0.152	0.104				
R^2					0.677	0.397	0.676	0.458
N	256	256	256	110	256	256	256	110

Average marginal effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use $2.25 per bushel of corn and drying costs of $0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

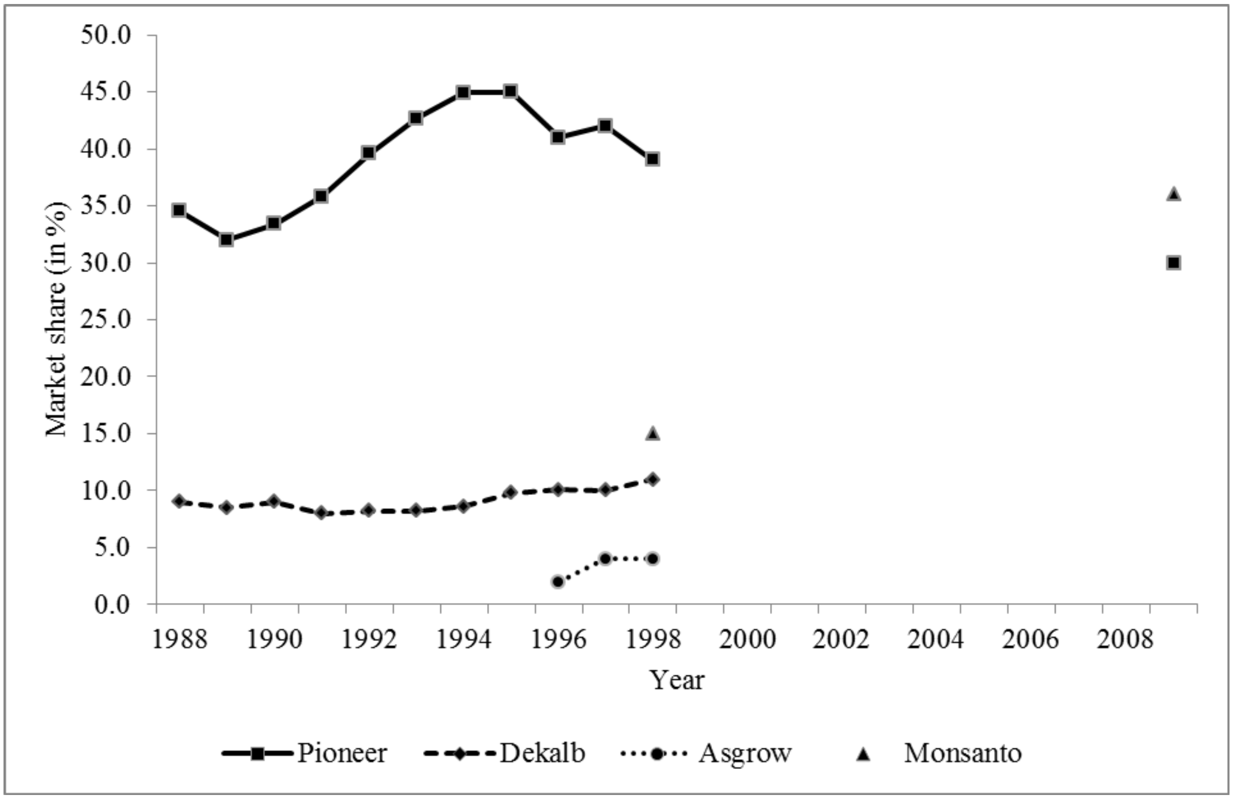
TABLE A-2 – CITATIONS AS A FUNCTION OF INCOME PER ACRE, DIRECT AND INDIRECT COMPARISONS, DEPENDENT VARIABLE IS CITATIONS PER PATENT, EXCLUDING FOUNDATIONAL PATENTS 4,607,453; 4,629,819; 4,731,499; 4,737,596; AND 6,433,261

	Direct comparisons				Indirect comparisons			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS	Neg. Bin.	Neg. Bin.	Neg. Bin.	OLS
% increase in yield per acre	0.255***	0.186***	0.249***	0.213***	0.126**	0.142***	0.111**	0.148**
	(0.075)	(0.065)	(0.077)	(0.073)	(0.053)	(0.049)	(0.049)	(0.073)
# of claims	-0.058	-0.021		-0.037	-0.046	-0.020		-0.028
	(0.040)	(0.031)		(0.032)	(0.043)	(0.030)		(0.034)
# of hybrids covered by this patent			-0.425				-0.185	
			(0.328)				(0.279)	
# of other patents covering this hybrid			0.945*				0.832	
			(0.542)				(0.529)	
Year of application		0.192				0.252*		
		(0.149)				(0.140)		
DeKalb	-0.116	0.491	-0.920*	-0.103	0.240	0.643	-0.546	0.253
	(0.675)	(0.723)	(0.554)	(0.822)	(0.711)	(0.641)	(0.521)	(0.901)
Other firm	-2.708***	-2.102**	-3.857***	-2.480***	-2.234**	-1.821**	-3.297***	-2.421**
	(0.984)	(0.869)	(1.095)	(0.904)	(1.025)	(0.830)	(1.063)	(1.007)
Time fixed effects	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Log likelihood	-327.809	-344.971	-327.608	-431.228	-331.855	-344.066	-331.697	-432.042
Pseudo R^2	0.068	0.019	0.068		0.056	0.021	0.057	
R^2				0.300				0.293
N	171	171	171	171	171	171	171	171

Average marginal effects. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10

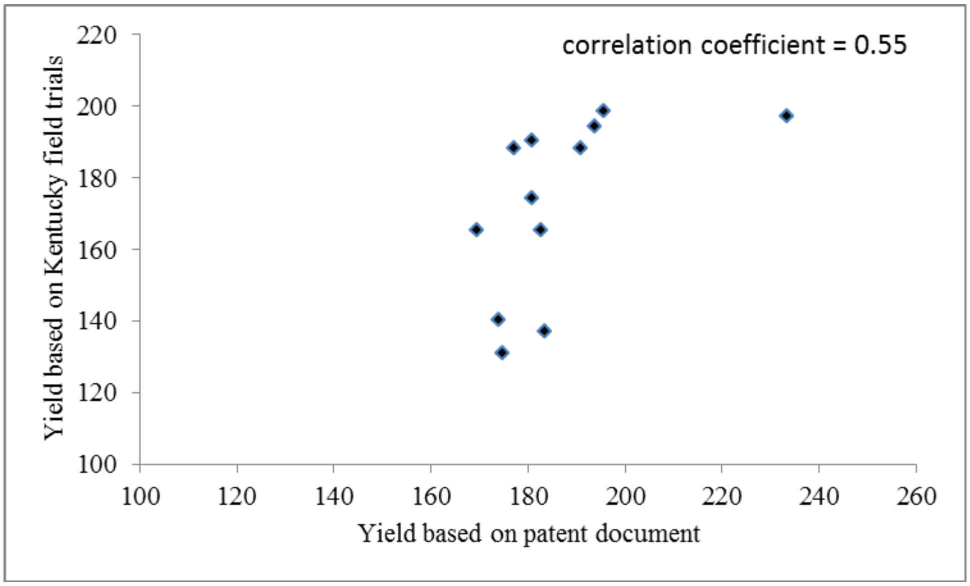
Notes: Data on yields were collected by a manual search of the full text of patent documents in subclass 800/320.1 available at www.uspto.gov. Data on income per acre incorporate information on the moisture content of a new hybrid in addition to its yield. Calculations use $2.25 per bushel of corn and drying costs of $0.04 per percent moisture above 15%. Price data from the United States Department of Agriculture's National Agricultural Statistics Service, available at www.nass.usda.gov. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. *Year of application* and *(Year of application)²* control for linear and quadratic time trends using 1985 as the base year. The average patent covers 1.25 hybrids, but a small number of patents cover up to 10 hybrids; the variable *# of hybrids covered by the patent* includes for such variation. Similarly, the average hybrid is covered by 1.2 patents, but one hybrid is covered by 3 patents; the variable *# of other patents covering this hybrid*, controls for such variation. Time fixed effects measure application year fixed effects for the full sample (columns 1-3, and 5-8); for regressions of DeKalb data only, two-year dummies are used.

FIGURE A-1 MARKET SHARE IN THE CORN SEED INDUSTRY



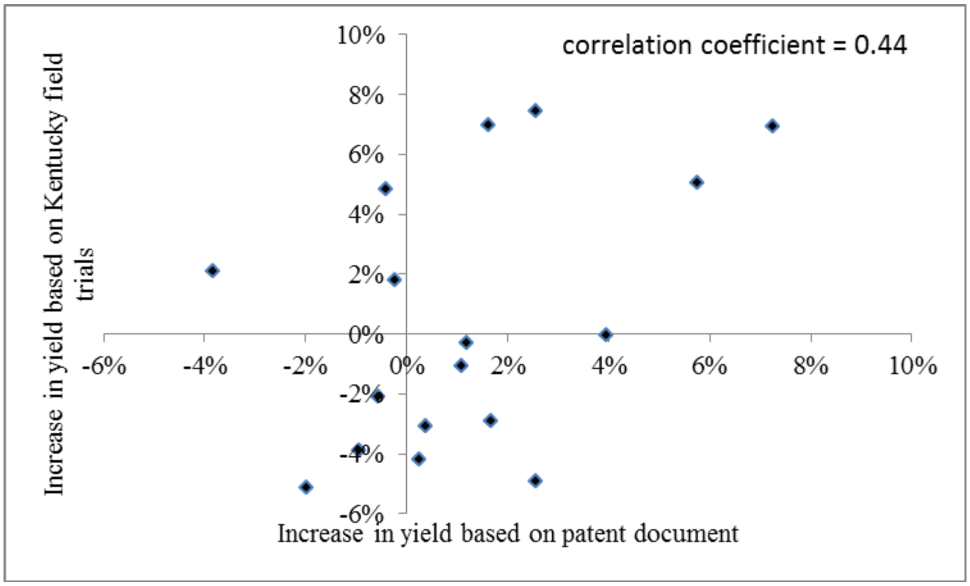
Notes: Data for the time period 1988 to 1998 from USDA Agriculture Information Bulletin #786. Data for 2009 are estimates from Deutsche Bank Research (as quoted in the Des Moines Register October 5, 2009).

FIGURE A-2 – COMPARISON OF ABSOLUTE YIELDS REPORTED IN THE PATENTS WITH ABSOLUTE YIELDS FROM INDEPENDENT FIELD TRIALS



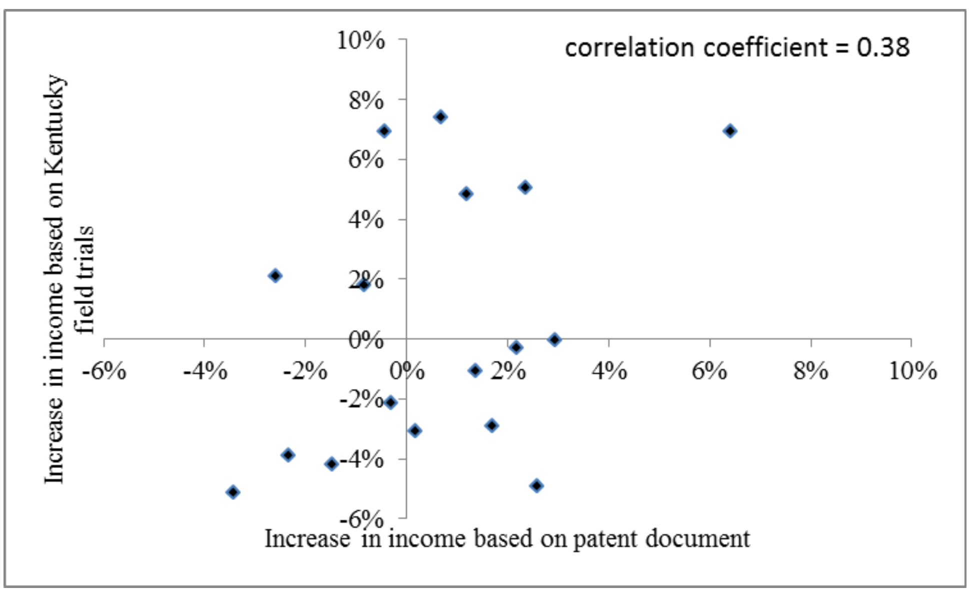
Notes: Each of the 12 data points represents a new hybrid for which we observe the absolute yield level in the patent document as well as in the Kentucky Performance Test reports. Since yield for the same hybrid vary from year to year, all absolute yield levels were normalized to 1998 yields level using data on the average yield in the U.S. Since we do not observe the information on the year in which the field trials were conducted for the data in the patent document, we use the year prior the year of application as theh estimate. Data on yields were collected by a manual search of the full text of patent documents. Independent test station data from the University of Kentucky (http://www.uky.edu/Ag/GrainCrops/varietytesting.htm). Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

FIGURE A-3 –INCREASE IN YIELD - COMPARISON OF BREEDER'S REPORTED FIELD DATA WITH INDEPENDENT FIELD DATA FROM THE KENTUCKY TEST STATION



Notes: Each of the 17 data points represents a new hybrid for which we observe a direct comparison with an existing plant in the patent document as well as in the Kentucky Performance Test reports. Data on yields were collected by a manual search of the full text of patent documents. Independent test station data from the University of Kentucky (http://www.uky.edu/Ag/GrainCrops/varietytesting.htm).

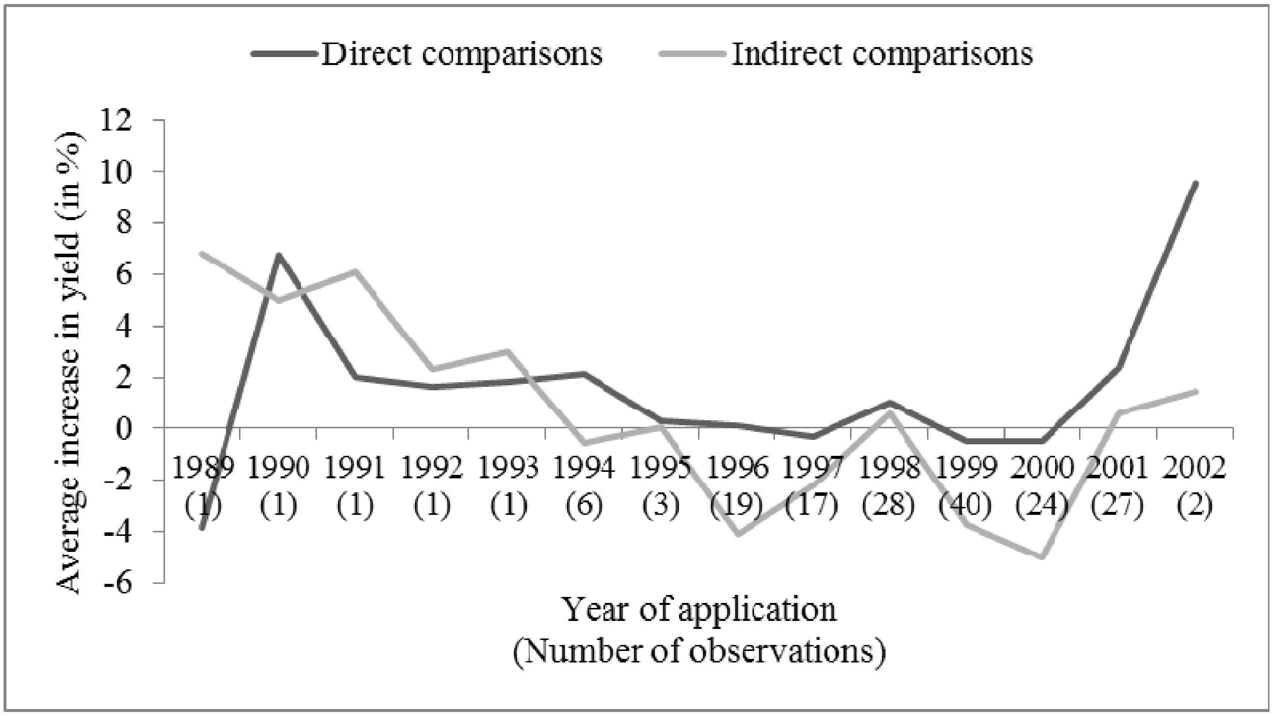
FIGURE A-4 –INCREASE IN INCOME – COMPARISON OF BREEDER'S REPORTED FIELD DATA WITH INDEPENDENT FIELD DATA FROM THE KENTUCKY TEST STATION



Notes: Each of the 17 data points represents a new hybrid for which we observe a direct comparison with an existing plant in the patent document as well as in the Kentucky Performance Test reports. Data on income per acre were collected by a manual search of the full text of patent documents. Increases in income per acre are also calculated based on independent test station data from the University of Kentucky

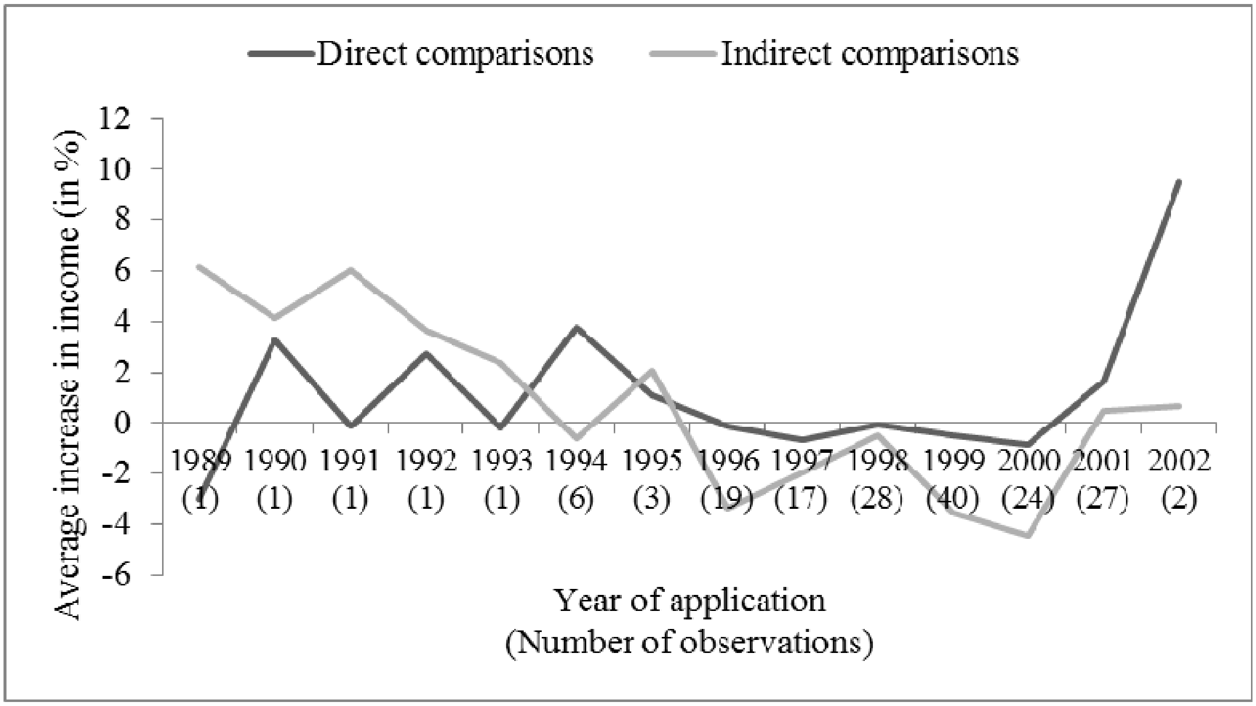
(http://www.uky.edu/Ag/GrainCrops/varietytesting.htm).

FIGURE A-5 – AVERAGE INCREASE IN YIELD BY YEAR OF APPLICATION
DIRECT VERSUS INDIRECT COMPARISONS



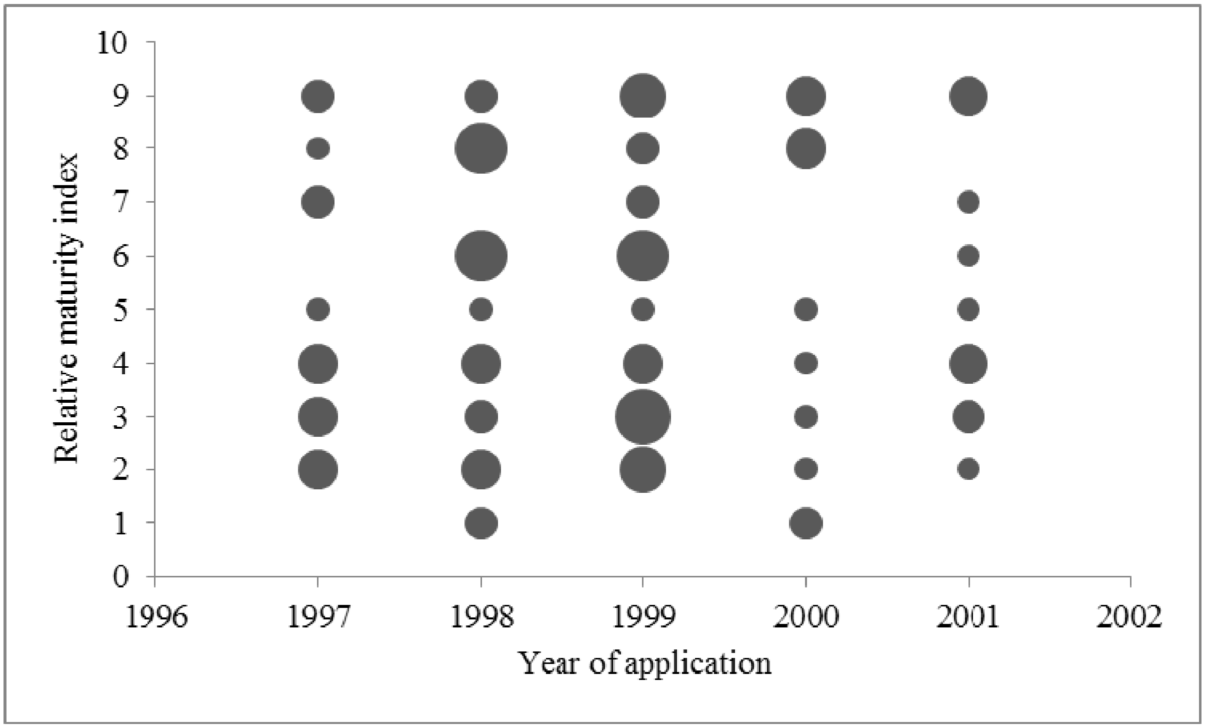
Notes: Average increase in yields by year of application for 171 patents granted for new hybrids in subclass 800/320.1 *Maize* (available at www.uspto.gov). Yields are normalized to 15.5 percent moisture at harvest. Data on yields were collected by a manual search of the full text of patent documents. Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

FIGURE A-6 – AVERAGE INCREASE IN INCOME BY YEAR OF APPLICATION
DIRECT VERSUS INDIRECT COMPARISONS



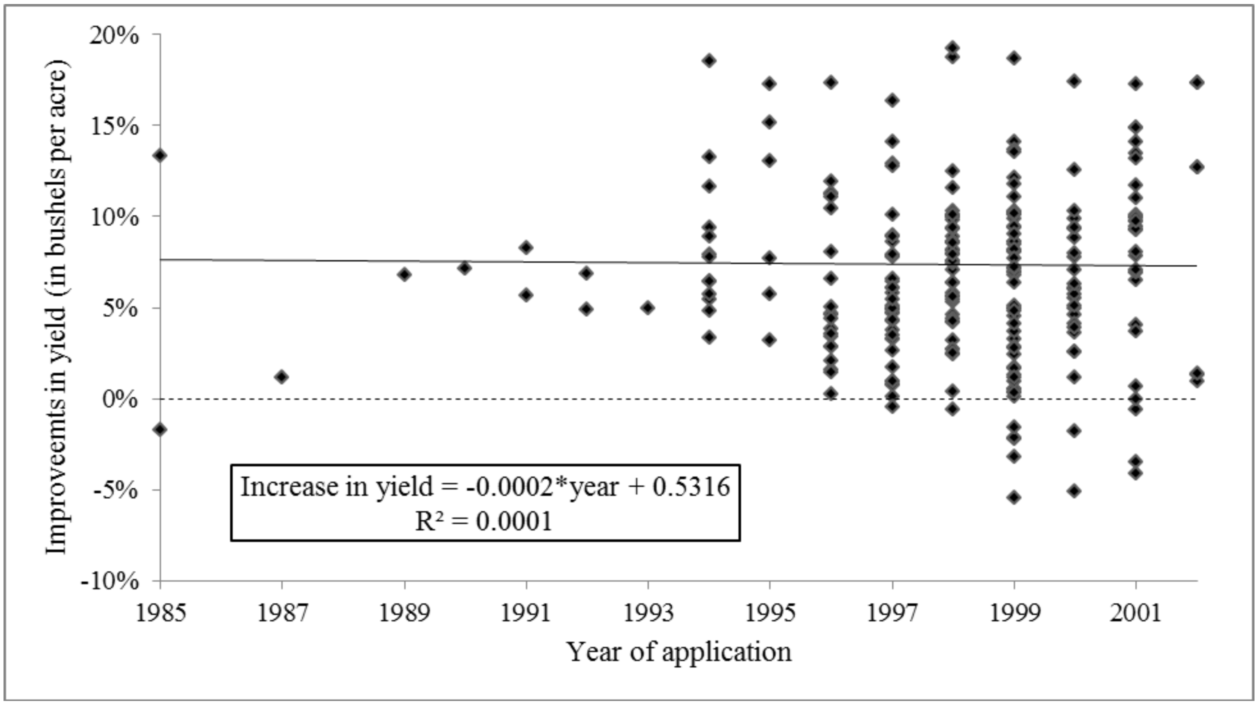
Notes: Average increase in income by year of application for 171 patents granted for new hybrids in subclass 800/320.1 *Maize* (available at www.uspto.gov). Yields are normalized to 15.5 percent moisture at harvest. Data on yields were collected by a manual search of the full text of patent documents. Data on U.S. averages from the United States Department of Agriculture (www.nass.usda.gov).

FIGURE A-7 – RELATIVE MATURITY OF NEW PIONEER HYBRIDS



Notes: Starting in 1997, Pioneer reveals the relative maturity of newly patented hybrids through the product code that they assign to their new hybrids (details on the assignment of product name available at www.pioneer.com/home/site/ca/products/product-naming-system). The second digit reveals the relative maturity level with a larger number implying a shorter relative maturity. Bubble size represents the number of observations ranging from 1 to 6. For example: there are 6 patents by Pioneer each having a relative maturity index of 3 in 1999. Data on all 89 patents with information on the relative maturity index in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 assigned to Pioneer (available at www.uspto.gov).

FIGURE A-8 – IMPROVEMENTS IN YIELDS LISTED ON NEW PATENTS BY YEAR OF APPLICATION



Notes: Improvements in yields are calculated by comparing the yield of the new hybrid with the lowest-yielding hybrid with similar characteristics. Calculations include both direct and indirect comparisons. Direct comparisons are read directly from the full text of patent documents; indirect comparisons are measured by linking the new hybrid through at least one other hybrid with a third hybrid that is not listed on the patent for the new hybrid. Data on all 256 patents in subclass 800/320.1 *Maize* granted between January 1, 1985 and March 8, 2005 (available at www.uspto.gov).

APPENDIX – DATA

The following is the description of the invention Pioneer Hybrid patent USPTO 4,731,499, issued on March 15, 1998 for Pioneer's hybrid seed 3790. Nearly all patents after this patent include a similar description of the invention and the breeding processes for hybrid corn.

Description: FIELD OF THE INVENTION

This invention is in the field of plant breeding, specifically hybrid corn breeding.

BACKGROUND OF THE INVENTION

The goal of plant breeding is to combine in a single variety/hybrid various desirable traits of the parental lines. For field crops, these traits may include resistance to diseases and insects, tolerance to heat and drought, reducing the time tocrop maturity, greater yield, and better agronomic quality. With mechanical harvesting of many crops, uniformity of plant characteristics such as germination and stand establishment, growth rate, maturity, and fruit size, is important.Field crops are bred through techniques that take advantage of the plant's method of pollination. A plant is self-pollinating if pollen from one flower is transferred to the same or another flower of the same plant. A plant is cross-pollinatedif the pollen comes from a flower on a different plant.

Plants that have been self-pollinated and selected for type for many generations become homozygous at almost all gene loci and produce a uniform population of true breeding progeny. A cross between two homozygous plants from differingbackgrounds or two homozygous lines produce a uniform population of hybrid plants that may be heterozygous for many gene loci. A cross of two plants each heterozygous at a number of gene loci will produce a population of hybrid plants that differgenetically and will not be uniform.

Corn plants (Zea mays L.) can be bred by both self-pollination and cross-pollination techniques. Corn has male flowers, located on the tassel, and female flowers, located on the ear, on the same plant. Natural pollination occurs in corn whenwind blows pollen from the tassels to the silks that protrude from the tops of the incipient ears.

The development of corn hybrids requires the development of homozygous inbred lines, the crossing of these lines, and the evaluation of the crosses. Pedigree breeding and recurrent selection breeding methods are used to develop inbred lines frombreeding populations. Breeding programs combine desirable traits from two or more inbred lines or various broad-based sources into breeding pools from which new inbred lines are developed by selfing and selection of desired phenotypes. The new inbredsare crossed with other inbred lines and the hybrids from these crosses are evaluated to determine which have commercial potential.

Pedigree breeding starts with the crossing of two genotypes, each of which may have one or more desirable characteristics that is lacking in the other or which complement the other. If the two original parents do not provide all of the desiredcharacteristics, other sources can be included in the breeding population. In the pedigree method, superior plants are selfed and selected in successive generations. In the succeeding generations the heterozygous condition gives way to homogeneouslines as a result of self-pollination and selection. Typically in the pedigree method of breeding five or more generations of selfing and selection is practiced. F.sub.1 .fwdarw.F.sub.2 ; F.sub.2 .fwdarw.F.sub.3 ; F.sub.3 .fwdarw.F.sub.4 ; F.sub.4.fwdarw.F.sub.5, etc.

Backcrossing can be used to improve an inbred line. Backcrossing transfers a specific desirable trait from one inbred or source to an inbred that lacks that trait. This can be accomplished for example by first crossing a superior inbred (A)(recurrent parent) to a donor inbred (non-recurrent parent), which carries the appropriate gene(s) for the trait in question. The progeny of this cross is then mated back to the superior recurrent parent (A) followed by selection in the resultantprogeny for the desired trait to be transferred from the non-recurrent parent. After five or more backcross generations with selection for the desired trait, the progeny will be heterozygous for loci controlling the characteristic being transferred,

butwill be like the superior parent for most or almost all other genes. The last backcross generation would be selfed to give pure breeding progeny for the gene(s) being transferred.
A hybrid corn variety is the cross of two inbred lines, each of which may have one or more desirable characteristics lacked by the other or which complement the other. The hybrid progeny of the first generation is designated F.sub.1. In thedevelopment of hybrids only the F.sub.1 hybrid plants are sought. The F.sub.1 hybrid is more vigorous than its inbred parents. This hybrid vigor, or heterosis, can be manifested in many ways, including increased vegetative growth and increased yield.
The development of a hybrid corn variety involves three steps: (1) the selection of superior plants from various germplasm pools; (2) the selfing of the superior plants for several generations to produce a series of inbred lines, which althoughdifferent from each other, each breed true and are highly uniform; and (3) crossing the selected inbred lines with unrelated inbred lines to produce the hybrid progeny (F.sub.1). During the inbreeding process the vigor of the lines decreases. Vigor isrestored when two unrelated inbred lines are crossed to produce the hybrid progeny (F.sub.1). An important consequence of the homozygosity and homogeniety of the inbred lines is that the hybrid between any two inbreds will always be the same. Once theinbreds that give the best hybrid have been identified, the hybrid seed can be reproduced indefinitely as long as the homogeniety of the inbred parent is maintained.

A single cross hybrid is produced when two inbred lines are crossed to produce the F.sub.1 progeny. A double cross hybrid is produced from four inbred lines crossed in pairs (A.times.B and C.times.D) and then the two F.sub.1 hybrids are crossedagain (A.times.B).times.(C.times.D). Much of the hybrid vigor exhibited by F.sub.1 hybrids is lost in the next generation (F.sub.2). Consequently, seed from hybrid varieties is not used for planting stock.

Hybrid corn seed can be produced by manual detasseling. Alternative strips of two inbred varieties of corn are planted in a field, and the pollen-bearing tassels are removed from one of the inbreds. Providing that there is sufficient isolationfrom sources of foreign corn pollen, the ears of the detasselled inbred (female) will be fertilized only from pollen from the other inbred (male), and the resulting seed is therefore hybrid and will form hybrid plants.

The laborious detasseling process can be avoided by using cytoplasmic male-sterile (CMS) inbreds. Plants of a CMS inbred are fertilized with pollen from another inbred that is not male-sterile. Pollen from the second inbred can contribute genesthat make the hybrid plants male-fertile. Usually seed from detasseled normal corn and CMS produced of the same hybrid seed is blended to insure that adequate pollen loads are available for fertilization when the hybrid plants are grown.

Corn is an important and valuable field crop. Thus, a continuing goal of plant breeders is to develop stable, high yielding corn hybrids that are agronomically sound. The reasons for this goal are obvious: to maximize the amount of grainproduced on the land used and to supply food for both animals and humans.