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Impact of Intellectual Property Rights in the Seed Sector on Crop Yield Growth and Social Welfare: A Case Study Approach

Dermot J. Hayes, Sergio H. Lence, and Susana Goggi
Iowa State University

A case-study approach is used to track research funding decisions made by the private seed sector. The three cases chosen provide a range of intellectual property protection (IPP) environments, crops, and companies, namely, (1) wheat in the United States and the European Union, (2) rootworm-resistant corn, and (3) hybrid tomatoes. The analysis suggests that IPP for US wheat is weak because growers are allowed to save seed and because breeders are responsible for the costs—both transactional and reputational—associated with enforcing those IPP rights that do exist. IPP in processed tomatoes is higher than in wheat because all processing tomatoes are now hybrids. However, the possibility that protected tomato varieties could be asexually reproduced weakens IPP and the incentive for the private sector to fund the basic research that might lead to high-value varieties. IPP in the US corn market is strong, and as a result, the private sector dominates in all aspects of the research process.

Key words: crop yield, genetic gain, intellectual property, seed sector.

> "I believe, in law, a seedling is regarded as the gift of God, and it would be hard to patent that; but could we not hope to have some law fashioned that would give a bonus to the man who does such skilled and valuable work as that which has come before us over and over again during the sessions of this conference?"[1]

By increasing the productivity of a fixed resource such as land, successful research (in the sense of covering its associated costs) that increases crop yields leads to an obvious improvement in social welfare. One would therefore expect that intellectual property (IP) incentives designed to reward the parties that produce innovations that increase crop yields would be widely viewed as beneficial. However, this is not the case. In a recent review article, Dunwell (2005) cites a large number of academic papers that highlight the alleged negative impacts of plant IP rights on the freedom to operate and on commercial opportunities for researchers and farmers in developing countries. Other issues cited in Dunwell's (2005) review are (a) concerns that private sector incentives lead to competition between the public and private sectors to the detriment of the public sector, (b) concentration among firms in the private sector due to a need for cross-licensing, (c) and a misallocation of research expenditures and genetic resources that might benefit industrially developed countries at the expense of countries under development.

Parayil (2003, pp. 981-982) also provides a comprehensive review of research conducted in the social sciences on the impact of private sector research and development, and he concludes that,

> "Private sector actors, which are predominantly multinational corporations, play the leading role in the innovation and diffusion of agricultural biotechnology related to the Genetic Revolution. The technological trajectory is shaped by the imperatives of private property institutions, market forces, global finance, and transnational (and in certain cases national) regulatory institutions. The contingencies and imperatives of economic globalization shape the technological trajectory. New plants and crops are being developed not to solve problems of hunger and deprivation, but mostly to increase shareholder values of companies that have invested heavily in R&D efforts in the biotechnology sector."

Moschini, Lapan, and Sobolevsky (2000) found positive social benefits from the introduction of Roundup Ready soybeans but conclude that one must adjust the welfare

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[1] *Professor Hansen's comments were presented at the Third International Conference on Genetics (organized by the Royal Horticultural Society), which was held in London in 1906. The conference is most famous for coining the term "genetics" by William Bateson as described in Dunwell (2005).*

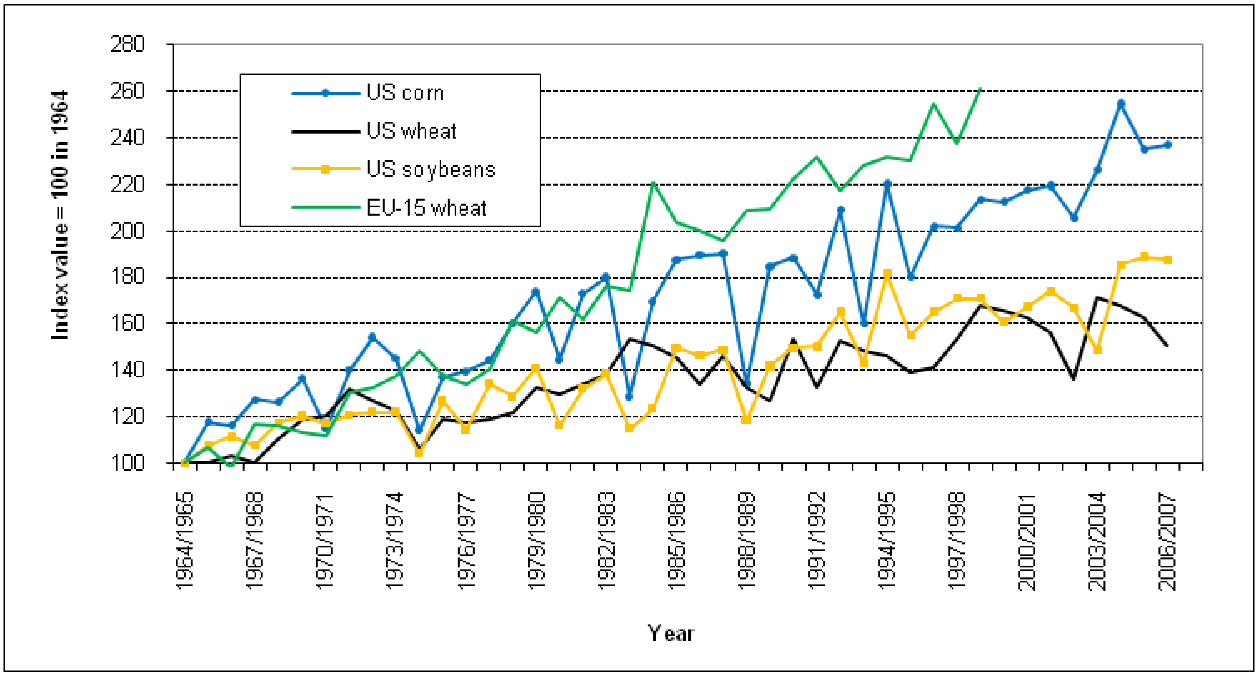

Figure 1. Yield index for US corn, US soybeans, US wheat, and wheat in the EU-15.

Note. The EU-15 consists of the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

measures down because the company that conducted the research captured a significant portion of this benefit.

Of the academic studies that have attempted to measure the impact of IP rights on crop yields, the one by Babcock and Foster (1991) draws a similar conclusion for tobacco. Carew and Devadoss (2003) find that, in the absence of a time dummy variable, the area seeded to varieties protected by Canada's Plant Breeders' Rights Act of 1990 did have a positive impact on crop yields for canola in Canada. However, the impact of plant breeders' rights is no longer significant when a time trend is included. These studies have typically estimated a crop yield function and then added the share of acres grown to crops developed in response to the IP protections provided to those crops as an explanatory variable.

In summary, most of the seed-sector-specific academic work that has been published in economics or the other social sciences to date has not been glowing in its praise of private sector research and the incentive structures that make this research possible. It is possible that authors believe that the benefits of this research are so obvious that they chose to focus on negative aspects simply to make a point. However, it may then follow that the combined impact of all these negative forces actually serves to obscure the message about benefits.

The purpose of the present article is to use a case-study approach to track research funding decisions made by the private sector, from the IP environment to the ultimate beneficiaries. We chose the three particular cases so as to provide a range of IP environments, crops, and companies. The first case we examine is the wheat sector in the United States and the European Union (EU). Here the IP environment appeared to be stronger in the EU. The second case involves the introduction of rootworm-resistant corn in the United States. This recently introduced trait was chosen because we expected that the scientists and financial decision makers involved would be available for interview. We were also aware that accurate yield data for corn plants having the rootworm-resistant trait were available. The third case involved the introduction of hybrid tomatoes. The motivation for this case was to determine whether research and development decisions and resulting crop yield impacts on vegetables were similar to those on major field crops such as wheat and corn.

Figure 1 helps explain the motivation of our research and the cases that we chose. Wheat yields in the EU have grown at a much faster rate than in the United States, as have corn yields in the United States relative to US soybean yields. These very large differences in the rates of yield growth have welfare implications.

To appreciate these welfare impacts, consider what would have happened had all four yields grown at the rate of US wheat yields. Alternatively, consider what US agriculture would look like if US soybean and wheat yields had grown at the same rate as corn yields.

Conceptually, gains in crop yields can be partitioned into (a) gains due to husbandry, fertilizer, pesticides, fungicides, etc.; and (b) genetic gains due to breeding. Thus, there are several possible explanations for the yield growth data shown in Figure 1. For example, it may be true that EU wheat yields have increased because wheat is grown on the best soils and because EU policy has encouraged fertilizer use. US wheat yields may have disappointed because wheat production has been moving to marginal land. There may be something fundamental about soybean biology that makes the production of hybrid seed difficult, thus restricting its yield growth compared to that of corn. However, it is also possible that differences in IP protection and in the degree of private sector research are partially responsible for the differences we observe. In order to untangle these differences, we need to get much closer to the data.

Case 1: Wheat Research in the United States and the European Union

Situation in the United States

The IP rules under which the private sector operated in the US wheat sector are described in Fernandez-Cornejo (2004). Prior to 1970, it was almost impossible for the innovator to realize any benefit from non-hybrid seeds such as wheat.[2] The 1970 Plant Variety Protection Act gave breeders the exclusive right to market a new variety for 18 years. This act resulted from work done by the Breeders' Rights Study Committee of the American Seed Trade Association. The act contained two exemptions that limited its applicability, namely, the research exemption and the farmer's exemption. The former allowed other companies to use protected seeds to develop new varieties, whereas the latter allowed saving and—under certain rules—selling seed grown from a protected variety. The act is enforceable only through the actions of the owners of the protected varieties. In 1994 the act was strengthened to require the farmer to obtain permission from the owner of the protected variety before selling the progeny of the protected seed. This permission requirement was extended slightly in 1995 to require a license.

A 1980 interpretation of the US Patent Act extended protection to genetically modified (GM) plants in the form of utility patents awarded under the Patent Act. These utility patents have been a source of protection for companies introducing GM corn and soybeans, but GM wheat has not been commercially introduced to date. In 1990, US-based Pioneer Hi-Bred International, Inc. (Pioneer Hi-Bred) discontinued the development, production, and sale of hard red winter wheat and donated its wheat germplasm collection to Kansas State University. The justification for this decision was reported as follows: "Pioneer officials cite what they call a weakness in the Plant Variety Protection Act that allows farmers to save seed for their own use in planting their next crop, which they say fails to adequately discourage farmers from also selling seed wheat they have grown to others" (*Omaha World Herald*, 1990). Although the company had not been spending significant resources on wheat research before the announcement (at least in relation to expenditures on corn research) the donated varieties were well received by Kansas State, and they formed the basis of two very successful seed lines from that institution, varieties 2145 and 2137 (Fritz, Martin, & Shroyer, 2002; Paulsen, 2000).

In our discussions with Pioneer Hi-Bred executives as part of this study, it was clear that the lack of interest in investing in new US wheat varieties was related to the lack of premiums available from the marketplace. In addition to the farmer's exemption described above, the executives also indicated that the transaction costs involved in enforcing the existing IP rules were relatively high, particularly given the tradition of saving and selling seed among wheat growers. In addition to the actual legal costs associated with enforcement, the brand name of the company is eroded when the company brings lawsuits against producers who are simply following tradition. One interesting aspect of this discussion is that soybean producers are viewed as being less opposed to paying royalties, in part because they are used to making these payments for corn and used to purchasing new seed each year.

Other wheat seed companies in the United States appear to have arrived at a similar conclusion, and, as a result, almost all of the research and variety releases for wheat are from the public sector (Fernandez-Cornejo, 2004). The report by Fernandez-Cornejo (2004) also

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[2] *Protections were introduced for asexually propagated plants by the Plant Patent Act of 1930 and to patentable improvements in general by the Patent Act of 1952, but neither of these acts contained language that extended IP to seeds.*

shows that soybean breeding research by the private sector was almost nonexistent prior to 1975 but gradually picked up so that it exceeded public sector research on soybeans in 1994. The interviews we conducted, as well as the data in Fernandez-Cornejo (2004), indicate that the availability of utility patents on GM soybeans has greatly increased the amount of private sector research since 1996 with the commercially successful introduction of glyphosate-resistant soybeans.

In summary, wheat breeders in the United States have not had access to effective IP protection, especially in areas of the country where farmers traditionally save seeds. Wheat breeders are also obligated to take action to implement any IP protections that are afforded to them, and the anticipated cost of this action appears to have deterred them from enforcing some of the existing rules. Even though the legal situation regarding soybeans is similar to that of wheat, lower transactions costs associated with enforcement prior to 1996 and the successful use of utility patents after that date have stimulated significant amounts of private sector research on soybean breeding.

Situation in the European Union

At first glance, the IP protection for wheat breeders in the EU is very similar to that of the United States. This is because the US Plant Variety Protection Act was amended in 1994 to bring it into conformity with the same rules that govern variety protection in the EU. The rules that govern variety protection in both geographic areas are now based on the International Union for the Protection of New Varieties (UPOV). However, the implementation of the UPOV rules is quite different. Under European regulation (see Council Regulation 2100/94, Article 14), farmers have a right to grow protected seed, but they are subject to payment of royalties. Payment rates are determined by national authorities. EU regulations and institutions have been created to ensure that the companies actually collect royalties that are due.

In the UK, the agency developed to organize and encourage these payments is known as Fair Play. This group was developed as a joint initiative between the British Society of Plant Breeders (BSPB) and the major farming unions in the UK in order to "combat farm-saved seed evasion."[3] Farmers can pay these fees in two ways. If they purchase seed, the payment is included in the invoice sent by the seed dealer and these payments are then forwarded to the seed company. If the farmer saves seed, then the farmer must pay the fee directly to the BSPB. The system is not perfect, and some farmers avoid paying fees by claiming that they are planting non-protected varieties. However, an estimated 90% of the royalties are collected, in part because farmers who do not pay are in violation of British law.

As an example of how the provisions that are included for royalty collection impact the industry, compare the reasons given above by Pioneer Hi-Bred for exiting the business of breeding hard red winter wheat with the following quote from the Fair Play site (FAQ section, under "How is plant breeding funded").

> "Until the early 1960s, plant breeding in Britain was largely confined to publicly funded research. This situation changed dramatically in the mid-1960s when Plant Breeders' Rights were introduced in the UK through the 1964 Plant Varieties and Seeds Act. This triggered a rapid expansion of plant breeding as a commercial enterprise in its own right, and paved the way for major advances in the performance, quality, and diversity of crop production in Britain."

The availability of a mechanism for collecting seed royalties allowed the main breeding agency to become privatized in 1987, when Unilever acquired the breeding and applied science resources of the Plant Breeding Institute. This group was later sold to Monsanto. Thirtle, Bottomley, Palladino, Schimmelpfennig, and Townsend (1998) provide a detailed history of public and private sector research efforts in the UK.

The situation in France and the rest of the EU is similar to that in the UK. In response to a question posed as part of our survey, Bernard LeBuanec, the French secretary general of the International Seed Federation, said:[4]

> "I think that there are two main reasons why wheat breeders are better protected in Europe and in France: seed certification is compulsory and breeders get royalties on all the certified seed and, as you say, there has been a royalty system in place for farm saved seed since the ratification by Europe of the 1991 Act of the UPOV Convention."

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[3] *See http://www.fairplay.org.uk/site/faq.html.*

[4] *E-mail communication on August 23, 2007.*

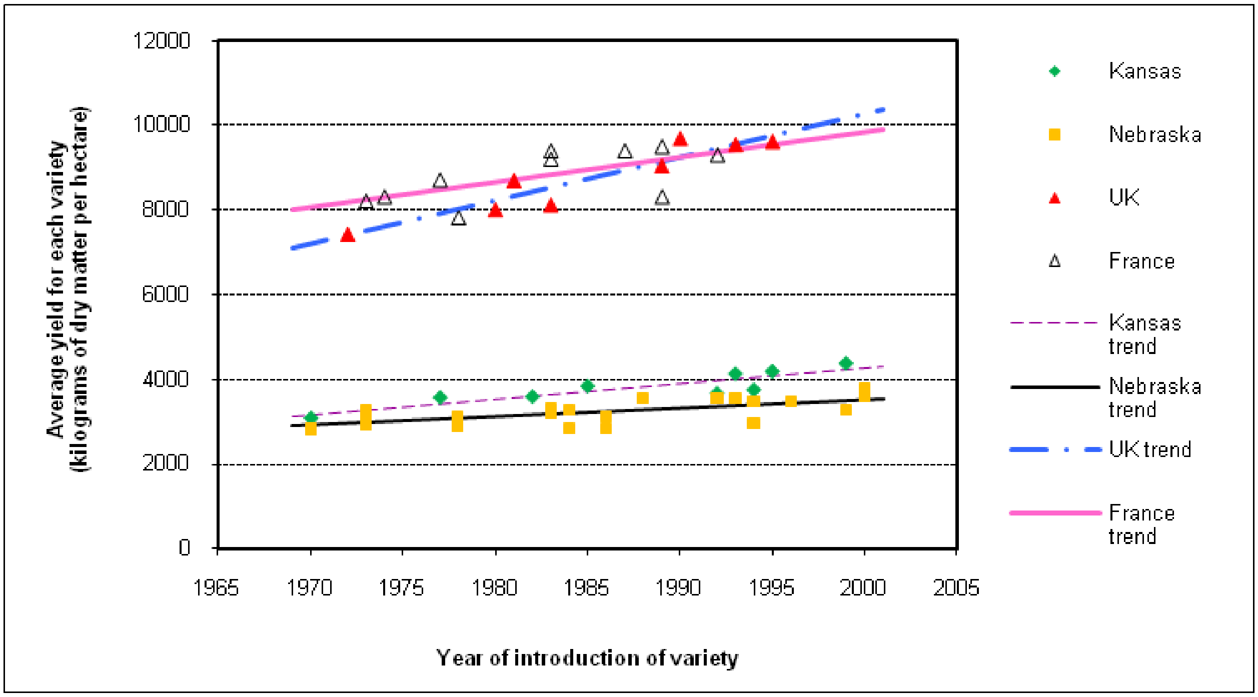

Figure 2. Average yields for wheat varieties introduced between the 1970s and 1990s in the United States, United Kingdom, and France.

Source: Constructed from data reported by Brancourt-Humel et al. (2003), Donmez, Sears, Shroyer, and Paulsen (2001), Fufa et al. (2005), and Shearman, Sylvester-Bradley, Scott, and Foulkes (2005).

Despite the similarities in the intent of the IP regulations, the systems in the United States and EU generate different incentive structures. Breeders in the EU will typically be paid a premium if their variety is used, and this gives them an incentive to innovate. Breeders in the United States can, in theory, collect this premium when a farmer sells protected varieties but not when a farmer uses the protected variety himself. In the United States, the responsibility for collection lies with the owner of the IP right, and there is a perception among seed company executives that the costs associated with collection, both legal and reputational, are likely greater than the benefits.

Impact of Wheat Breeding Programs in the United States and European Union

Figure 1 clearly shows that wheat yields in the EU have increased much faster than in the United States, both in absolute and proportional terms. However, as we mentioned earlier, this gain may be due to changes in land quality, fertilizer use, or even agricultural policy. We were fortunate to find four studies that controlled for all of these extraneous factors and that measured the increase in yields due to breeding between the 1970s and the 1990s. The term used for measuring the impact of breeding is *genetic gain*, and it is defined as “the increase in productivity achieved following a change in gene frequency affected by selection” (Zaid, Hughes, Porceddu, Nicholas, 2001, pp. 124).

Two of these studies, by Donmez et al. (2001) and Fufa et al. (2005), evaluated the rate of genetic gain in winter wheat cultivars that are typically grown in the US Great Plains. Donmez et al. (2001) conducted the field experiments in Kansas, whereas Fufa et al. (2005) did so in Nebraska. Another study, by Shearman et al. (2005), evaluated the rate of genetic gains among wheat cultivars grown in the UK, and a fourth study, by Brancourt-Hulmel et al. (2003), focused on genetic gains for wheat in France. The yield data reported by these four studies for varieties introduced between the 1970s and the 1990s is represented graphically in Figure 2. This graph also shows the corresponding trend lines obtained by fitting ordinary least squares regressions of variety yields against the year of introduction of the respective cultivars. Figure 2 shows that wheat yields are substantially higher in the UK and France than in the United States over the period analyzed. Further, annual genetic gains are also higher in the European countries than in the US. Yield regressions estimated annual genetic gains of 20.5

kg of dry matter per hectare in Nebraska, 36.5 kg of dry matter per hectare in Kansas, 59 kg of dry matter per hectare in France, and 103 kg of dry matter per hectare in the UK.

While it is impossible to prove causation from the data shown here, it is possible to conclude that the stronger IP incentives in the EU are associated with higher genetic gains. Given the small resources devoted by the public sector in the United States to wheat breeding, the rate of genetic gain is impressive. But as the data in Fernandez-Cornejo (2004) show, when properly motivated, the private sector can bring vastly more resources to breeding programs than the public sector has been able to provide to date.

Case 2: Development of Rootworm-Resistant Corn in the United States

Hybrid corn is the direct opposite of wheat in terms of the ability of US companies to capture IP premiums. Historically, this has been true because of the biologically enhanced yield effect known as hybrid vigor. It is also true because farmers must purchase new seed every year to take advantage of the higher yields associated with hybrid seed. Not surprisingly, genetic gains in US hybrid corn have been significant. Duvick, Smith, and Cooper (2004) estimate annual genetic gains of 77 kg per hectare in corn hybrids introduced between 1930 and 2001. They argue, based on a large number of studies, that annual genetic gains have been on the order of 65 to 75 kg per hectare over the last 70 years. Furthermore, the annual genetic gains appear to have been roughly constant throughout the whole period. Thus, annual genetic gains of US hybrid corn are intermediate between the genetic gains reported in wheat in the UK and the ones in wheat in France.

More recently, the historic IP protection rights for hybrid corn have been strengthened as companies have taken out utility patents on GM varieties. These utility patents have created opportunities for seed companies to license the trait to other companies, resulting in a greatly extended market share and resulting fees for the trait.

The purpose of this case study is to trace the development of a new genetic trait—resistance to corn rootworm (CRW)—from the internal company decisions to the final impact on social welfare. We were fortunate in this regard because two of the companies involved in the introduction of CRW-resistant varieties allowed us access to executives that were aware of the scientific and financial decisions that lay behind the product. We were also able to find detailed data on the farm-level impacts from research by Alston, Hyde, Marra, and Mitchell (2002) and from state extension personnel.

The CRW Problem

CRWs complete their life cycle in one year. Adults feed on pollen, silks, and leaves of corn plants from July through September. Females tend to mate and lay eggs in the field where they feed and will lay more than 1,000 eggs on average in clutches of about 80 eggs each over several weeks in the summer. Most eggs are laid in the upper six inches of soil; however, females will lay in deep cracks in dry years. Eggs typically remain dormant until the following spring. CRW larvae hatch in late May and early June and feed on the roots of corn plants for approximately three to four weeks until they pupate.[5]

Currently there are two important economically damaging CRW species, namely, the western (*Diabrotica virgifera virgifera*) and the northern (*Diabrotica barberi*) CRWs. These species cause similar damage to corn and have overlapping geographies, stretching from South Dakota and Kansas across the entire Corn Belt and into New England.[6]

Both of these species have behavioral “variants” that have recently adapted to allow them to flourish in the corn-soybean rotation system that is common throughout much of the Midwest. Annual rotation of corn and soybeans traditionally has been relied upon to control rootworm infestations. In the past, the life cycle of western and northern CRWs could be interrupted by annual rotation of corn and soybeans. Because neither western nor northern CRW adults were known to lay eggs in soybean fields, a grower could plant corn after soybeans without concern about rootworm larvae in the field. The larvae that hatched in soybean fields could not survive on soybean roots, so they died. However, within the past two decades, western CRWs have developed variants that lay eggs in soybean fields, even though they continue to lay eggs in cornfields. When variant western CRW larvae hatch in corn planted after soybeans, they are able to cause damage to the roots of the first-year corn that follows the soybean crop. Northern CRWs, on the other hand, have developed the capability to allow their eggs to remain dormant for extended periods (so-called extended or prolonged diapause), which allows eggs to remain viable through the season when soybeans

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[5] *http://ipm.uiuc.edu/fieldcrops/insects/corn_rootworm/factsheet.html*

[6] *http://www.dowagro.com/herculex/pest/corn.htm*

are planted in a field. When variant northern CRW larvae hatch in corn planted after soybeans, two years after eggs were laid, they are able to survive on and cause damage to the roots of first-year corn. Each of these variants has a significant range, with the soybean variant being most prevalent in Illinois and Ohio and the diapause variant being most prevalent in Iowa, Minnesota, and South Dakota.[7]

Corn producers currently have access to three transgenic events designed to control CRWs—YieldGard Rootworm (owned by Monsanto), Herculex RW (owned by Dow AgroSciences and Pioneer Hi-Bred), and Agrisure RW (owned by Syngenta). In areas where rootworm pressure has been high, the YieldGard and Herculex CRW-resistant events have been widely used.

First commercialized by Monsanto in 2003, YieldGard Rootworm corn is modified to protect against rootworm larva that can weaken and destroy the root nodes and brace roots of corn. Damage to the underground root system reduces the plant's ability to absorb nutrients, particularly in drought situations. Damage to the brace roots also reduces the ability of the corn to withstand wind. This damage is sometimes more important than feeding injury on the main root system because the entire crop can be lost if wind causes the corn to lodge. Even if the entire crop is not lost, lodged plants increase costs by slowing harvest. In addition to larval feeding damage, the adult beetles can also cause yield losses by clipping the silks, thereby reducing kernel set.

Interviews with Corporate Executives at Monsanto and Pioneer Hi-Bred

The relatively recent introduction of the CRW-resistant events means that several of the individuals responsible for decisions about research and commercial introduction of rootworm-resistant corn are still working at these companies. This institutional memory is of great value because we can get a sense of the way key decisions were made.

We interviewed managers from Monsanto and Pioneer Hi-Bred who had been involved in the CRW-resistant events.[8] We signed confidentiality agreements with both companies, and, in addition, we agreed to limit our discussions to situations that were already in the public domain. Of critical importance to us, the individuals we met were very much aware of the location of publicly available information. This allowed us to find key information sources from among thousands of possible sources. For example, executives at these firms typically provide investors with detailed product information that is released for the first time at meetings of stock analysts. These presentations are then loaded at company websites along with other news stories. By meeting with the individuals involved in much of the work described in these presentations, we were able to find key data that might otherwise have eluded us.

Much of what we learned at these meetings conformed to our original expectations. Decision makers clearly have stockholders in mind when investing scarce corporate resources. They make decisions under a risk-return framework that is very similar to that modeled in the finance literature, and they fund research products with a positive expected return. Research on corn is viewed very favorably because of the ability to capture a return on this research through IP protection. Expected return on traits is judged based on the ability of the company to charge a premium for that trait multiplied by the expected number of units sold containing that trait.

Some of these conversations also provided us with insights that we had not anticipated. We describe these below because they inform the results we present later.

Lack of Accurate Measures of Research Costs

We had expected the companies to have an accurate measure of what it took to bring the CRW-resistant trait to market. We discovered that with basic research of this type, companies have problems in accurately allocating costs to specific projects. In hindsight, this makes sense because this type of research is risky and may not result

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[7] *http://www.dowagro.com/herculex/pest/corn.htm and http://ipm.uiuc.edu/bulletin/article.php?id=635*

[8] *Executives who were interviewed at Pioneer were Enno Krebbers (Intellectual Property Strategy Director), John Grace (Licensing Manager), Louise Foutch (Senior Intellectual Property Counsel), Marv Wilson (Director, North America Product Strategy), Joe Keaschall (Research Director), Rafael Herrmann (Research Director-Insect Control), Murt McLeod (Agronomy Research Scientist), Paula Davis (Senior Manager—Insect & Disease Resistance Traits, Pioneer Strategic Planning), Mike DeFelice (Senior Manager, Pioneer Strategic Planning), and Stephen Smith (Research Fellow). Executives at Monsanto included Jim Tobin (Grain Industry Relation Lead), Clint Pilscher (Corn Insect Technology Manager), Eric Sachs (Global Scientific Affairs Lead), Ty Vaughn (Agronomics Traits Team Lead), Corby Jensen (Corn Insect Technology Manager), Jim Zardnt (Business Development Lead, and Corn Trait Lead when CRW was commercialized), Graham Head (Global IRM Lead), Sam Eathington (Line Development Breeding Lead), and Eloy R. Corona (Trait Stewardship Lead).*

in a successful market product but if successful may lead to unanticipated opportunities that were not even budgeted at the initiation of the project. Both companies did provide us with an educated guess of one hundred million dollars as the total cost of bringing a new biotech trait to market. This guesstimate included costs associated with registering the new trait, as well as start-up marketing efforts. This amount coincides with the figure reported in Bell and Shelman (2006), who in addition report a period of approximately ten years for the whole process from initiation of the research until successful introduction of the commercial product.

Pricing Decisions

Biotech traits such as resistance to CRW involve enormous fixed costs as described above. However, once these traits are developed and commercialized, the marginal cost of *including the trait in a unit of seed* is very close to zero. In fact, one executive said that the marginal cost was probably negative because maintaining the trait as a separate product line added to inventory control costs.[9]

The information we collected on low or zero marginal costs helped us understand the way these products are priced. We had expected that the first company licensed to sell a new trait would price that trait at a value that is just below the full expected value of this trait to a representative or average producer. For CRW resistance, this value would include an assessment of the costs of buying and applying the alternative pesticide, any extra yield advantage associated with the trait in excess of that available from the pesticide applied to conventional seed, and a charge for any convenience and flexibility associated with the new trait. We had anticipated that these expected value calculations would be similar for all producers who currently applied the pesticide.

It was clear from our interviews with both groups of executives that these traits are not sold based on their expected value to a representative producer. Executives were aware that producers differed widely in their willingness to pay a premium for the trait. This difference across producers is due to differences in perception among wary, risk-averse producers who must make purchase decisions before they know the insect pressure, expected per-bushel price of the crop, or actual weather patterns and the weather-related value of insect resistance. Companies must charge all producers the same price for the seed regardless of the full value of the trait to each producer. They charge a price consistent with the long-run survivability of the firm, so that a marginal or target producer is just willing to purchase the trait. Of all the producers who buy the trait, the marginal producer will obtain the least amount of value. This means that all other producers who end up buying this trait will obtain more value from the trait than this marginal producer.

The two pricing models described above lead to different price premiums. Under the first model, the premium would be the full expected value to the representative producer. Under the second one, the trait would be priced so as to attract marginal producers.

We were able to collect data on the actual premiums for the CRW-resistant trait to determine which of these pricing models were followed in practice. We had access to the ex-ante expected value that appears similar to the kind of information that the company would have had when it decided on the premium level and we also had access to the actual premiums that were charged. We also followed this up with an ex-post evaluation to ensure that the ex-ante analysis of producer value was accurate.

Ex-Ante Benefits

In a paper written before the commercialization of the CRW-resistant trait, Alston et al. (2002) presented some very detailed farm-level calculators on the likely benefits of Monsanto's YieldGard Rootworm trait. Their work is all based on data for the year 2000. They used an extensive database of the actual incidence of CRW problems across the United States. They also had access to experimental data on various CRW control treatments, including YieldGard Rootworm. In addition, they conducted a survey of 601 corn farmers to evaluate the willingness of these producers to pay for benefits such as human and environmental safety, equipment cost savings, and handling and labor time savings.

It seems probable that decision makers at Monsanto knew about the results of the Alston et al. (2002) study when they made decisions about the premium to charge for their event. This appears likely because Alston et al. (2002) cite Monsanto as the source of some of their data, and also because the authors thank Monsanto personnel (Anderson, Pershing, and Mattingly) for advice.

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[9] *Note, however, that the arrangements involving dealers and seed companies to sell varieties incorporating a new trait may include commissions based on sales revenue. If this is so, then such commissions should be considered a marginal cost of selling the trait.*

Table 1. Estimate of the Midwest retail price premium for YieldGard Rootworm and associated company-wide sales of this trait.

	2003	2004	2005	2006	2007
Per-unit premium for CRW-resistant trait, as reflected in the YGRW premium for DKC60 ($/unit)	88.10	57.00	48.00	42.00	43.00
Per-acre premium for CRW-resistant trait, as reflected in the YGRW premium for DKC60 ($/acre)	32.63	21.11	17.78	15.56	15.93
Estimated area planted with Monsanto CRW-resistant traits, including stacked varieties (million acres)	0.4	1.8	4.1	10.0	20.8
Estimated gross return to Monsanto and associated network of seed companies and dealers (million $)	13	38	73	156	331

Sources: Unit premiums collected from a database of publicly available seed price cards. Monsanto acres for 2003 through 2006 are reported in Casale (2007a, pp. 12; 2007b, pp. 7).

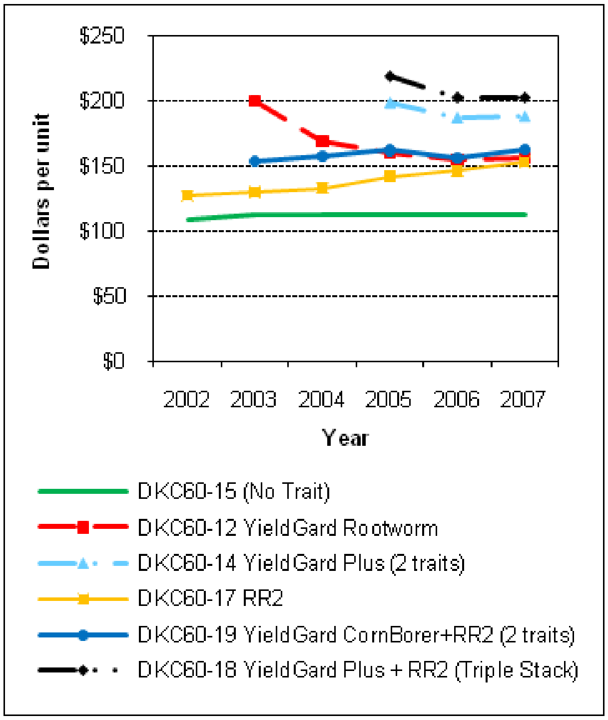

Figure 3. Midwest retail price per unit of DKC60 with different traits.

Finally, Monsanto used this study in its submission to the Environmental Protection Agency documenting the efficacy of the trait (Monsanto, 2007).

Alston et al. (2002) assumed that Monsanto would charge a seed premium that was equal to the cost of controlling CRW with insecticides, averaging $12.43 per acre nationwide and $13.52 per acre in "the heartland." They also assumed that any additional yield benefits over and above those that were available under existing treatment alternatives would be allowed to accrue to the producer. They calculated the value of these additional benefits at $16.49 per acre (assuming corn was worth $1.85 per bushel). Their survey results also suggested that producers would pay an additional $6.61 per acre for convenience and safety. Their estimate of the total corn area treated for CRW is 13.8 million acres and their estimate of the total benefits to producers from usage of the CRW-resistant trait on all of such an area is $289 million.

Ex-Post Benefits

We were able to find publicly available data on the actual prices for a unit of seed containing the YieldGard Rootworm trait sold by Midwestern seed dealers for several versions of Monsanto's seed lines DKC60 in recent years. These data are shown in graphical form on a per-unit basis in Figure 3 and on a per-acre basis in Table 1.[10] To measure the premium charged for the CRW-resistant trait, we subtracted the per-unit charge for DKC60-15 with no CRW-resistant trait from the premium charged for DKC60-12 with the trait. To express this premium on a per-acre basis, we divided the per-unit premium by 2.7 acres per unit.

The estimates in Table 1 show that the $32.63 per-acre premium for the CRW-resistant trait in the year of introduction was much higher than the cost of controlling CRW with the next-best alternative technology, projected by Alston et al. (2002) at $13.52 per acre in the Midwest. This high premium was associated with seed scarcity, as the company was ramping up production (Sankula & Blumenthal, 2004).[11] Once the seed

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[10] *The per-unit price of the Dow AgroSciences/Pioneer Hi-Bred product Herculex was approximately similar to the Monsanto product once the Herculex brand trait was introduced in 2006. For example, the per unit price of the corn seed 2G675 HRXRW,LL equaled $163 per unit in 2006 and $147 in 2007, whereas the triple stack product 2G677 HXX,LL sold in the range of $175 to $187 in its first year, 2007.*

became widely available, the premium rapidly fell to a range of $15 to $16 per acre. This corresponds very well to the Alston et al. (2002) projection of the average cost per acre of the next-best alternative to control CRW, especially when one factors in the inflation in pesticides and application costs between 2000 and 2006. This suggests that the company knew that it would be selling the seed trait at well below the anticipated benefit to the producer.

Sales of the trait remained below the 13.8 million acres projected by Alston et al. (2002) until 2007, when sales exceeded this projected level by a large amount. The estimated gross annual return to Monsanto and its network of seed companies and dealers also remained below the Alston et al. (2002) projection of $171 million until 2007, when this projected amount was exceeded by $160 million.

It is too early to compare the actual yield impacts of the CRW-resistant traits in a statistically valid way, because on-farm yield experience will be dictated in part by weather events specific to each year. However, there is some anecdotal evidence to suggest that the expected yield impacts have been greater than those anticipated by Alston et al. (2002). An evaluation of CRW control products in Iowa indicated that YieldGard Rootworm hybrids averaged yields between 21 and 33 bushels per acre, or 18% higher compared to the insecticide treatments (Rice & Oleson, 2005). Similar trends were also noted in Indiana (Krupke, as cited in Sankula, 2006). Steffey and Gray (2007, pp. 122-123) provide the following discussion in a recent publication:

> “In our corn rootworm product efficacy trial conducted last year (2006) in Urbana, almost every soil insecticide we tested prevented significant rootworm larval injury, despite very heavy corn rootworm pressure in the untreated check plots (average node-injury rating = 2.95). Yet, non-published data revealed that the YieldGard RW hybrid (node-injury rating = 0.96) had the highest yield (by a large margin) in the trial, significantly greater than the yields of all plots treated with soil insecticides about 56 bushels per acre greater than the average yield of four plots treated with granular soil insecticides. This lopsided yield edge in favor of the Bt treatment occurred even though the soil-insecticide treatments were applied to the isoline of the Bt corn rootworm hybrid. (This yield disparity between Bt corn and plots treated with soil insecticides was not apparent at our DeKalb site in 2006.)
>
> Results such as our results from the Urbana experiment in 2006 have been reported by other investigators as well, raising questions about the utility of root ratings as the sole determinant of rootworm injury and their relationship with yield. Consider the following questions:
>
> Why have large yield differences between Bt corn and plots treated with soil insecticides occurred when the rootworm-injury ratings were essentially equivalent? In fact, why would Bt corn out-yield isolines treated with soil insecticides even when the Bt corn hybrid had more rootworm injury?”

Our discussion with seed company executives suggests that these additional yield increases are real and that they can be explained by the ability of the new traits to allow the full genetic capability of the plant to be expressed. The logic is that traits protect against pests and diseases that cause plant stress. When these stresses are eliminated, genetic potential that previously had not been fully expressed due to plant stress can now manifest. If this logic is correct, then trait research like CRW-resistance may end up motivating more traditional breeding.

The Impact of Ethanol

Possibly the most important ex-post benefit of the CRW-resistant varieties is associated with the growth of ethanol production that began to make itself apparent in corn futures prices in the fall of 2006. This demand-side impact has caused corn prices to double from the $1.85 per bushel estimate used by Alston et al. (2002). This price impact doubled the producer benefit from the anticipated levels, and to the extent that yield response is also higher than anticipated, the overall expected returns to the producer likely far exceed those originally anticipated by Alston et al. (2002).

The ethanol price impact caused US corn plantings to increase from 81 million acres to 93 million acres in 2007. Many of these acres were added by growing corn in fields that had grown corn in the previous year. Producers were willing to switch from their traditional

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11. *The small acreage planted with the CRW-resistant trait (0.4 million acres) provides additional evidence of its scarcity in the year it was introduced.*

corn-soybean rotation because the CRW-resistant varieties provided them with an easy alternative to crop rotations as a way to control rootworm.

Conclusions from the CRW-Resistant Case

Companies that made decisions to develop and introduce corn varieties resistant to rootworm did so in anticipation of a high market-based return. The initial investments made by these companies were huge relative to typical university seed research budgets, and total investment in this sector may well have exceeded three hundred million dollars. These investments were justifiable because the companies could reasonably expect that the IP they were developing would be highly protected.

Decisions about the level of premium to charge for the CRW-resistant trait were made in an environment of zero marginal costs. The trait premium was set at a level that was well below the best available ex-ante estimate of the value of this trait to a representative farmer. As a result, sales have greatly exceeded the number of total acres that had earlier been treated with insecticides.

Our ex-post analysis suggests that gross returns to the company that initially developed the technology were in the range anticipated prior to 2007, and at that point the annual gross return to the company exceeded the original investment. The expected yield gain to producers appears to have been underestimated in the field trials undertaken prior to the release of the trait.

The upheaval in the US corn market driven by the ethanol boom in 2007 essentially doubled the net benefits of the CRW-resistant technology to farmers and to the original company. The widespread availability of this trait also helped the world economy adjust to the US ethanol boom by allowing Midwestern producers to move away from their traditional corn-soybean rotation and into corn-on-corn rotations.

Case 3: Hybrid Processing Tomatoes

For this case we followed a procedure similar to the one we used for CRW-resistant corn. We combined a literature and data review with interviews. The interviews were with executives from Seminis, the world's largest developer, producer, and marketer of fruit and vegetable seeds.[12]

Tomatoes are grown in most countries, with China, India, Turkey, Egypt, and the United States harvesting the most acres (Food and Agriculture Organization of the United Nations [FAO], n.d.). Within the United States there are two distinct markets, namely, fresh consumption and processing. Fresh tomatoes are grown throughout the United States so as to minimize haulage costs to the retail sector. Florida and California are the top two producers of fresh tomatoes. Processing tomatoes are used in tomato sauces, tomato paste, barbeque sauces, and a wide range of other products. The processing tomato industry is located primarily in the Central Valley of California. The area planted with processing tomatoes exceeds the area planted with fresh tomatoes in that state by a factor of six to one (US Department of Agriculture, National Agricultural Statistics Service [NASS], n.d.).

To the best of our knowledge, the only published study analyzing genetic gains in yields in US tomatoes is by Grandillo, Zamir, and Tanksley (1999). However, the method used by these authors is not consistent with the method used by the studies focusing on genetic gains in wheat and corn reported earlier. The fundamental difference between the study by Grandillo et al. (1999) and the other studies is the nature of the data. The wheat and corn data were obtained from experiments specifically designed to measure genetic gains, whereas the tomato data were obtained from field trials aimed at evaluating the differences across varieties within a set that changed over time. Although a handful of tomato varieties were planted over several years as long-term checks,[13] the set of tomato varieties being tested evolved through time, with more recent varieties tending to replace older ones as the latter were being rendered obsolete by the former. Furthermore, the number of varieties and the location of tomato field trials changed from year to year because of budgetary constraints and other reasons.

Because of the type of data available, Grandillo et al. (1999) measured genetic gains in tomatoes as the annual change in yields in the mix of non-check varieties, relative to the annual change in yields in the long-term checks. They concluded that there had been genetic gains in tomato yields because they found that the yields of non-check varieties had increased over time relative to the long-term checks. However, their conclusions are

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[12] *We spoke to Seminis executives Marlin Edward (Chief Technology Officer), Manuel Rosas (R&D Director Breeding), and Lindsay Hutchinson (Business Analyst Manager).*

[13] *A long-term check is a variety that is planted year after year, so that all newer varieties can be compared to the same base variety.*

Table 2. Ordinary least squares regressions of yields for tomato varieties on year of variety introduction, year of trial, and years between first and last trials, for trials conducted in California between 1980 and 2008.

Regressions:	**(A)** $Yield_{Var,T} = \beta_0 + \beta_I\ IntroductionYear_{Var} + \beta_T\ T + error_{Var,T}$								
	(B) $Yield_{Var,T} = \beta_0 + \beta_P\ TrialPeriodX_{Var} + \beta_I\ IntroductionYear_{Var} + \beta_T\ T + error_{Var,T}$								
Coefficient	**Regression (A)**	**Regression (B), with *X* in *TrialPeriodX*$_{Var}$ as defined below**							
		***X* = 1**	***X* = 2**	***X* = 3**	***X* = 4**	***X* = 5**	***X* = 6**	***X* = 7**	***X* = 8**
β_0	–344***	–347***	–347***	–338***	–348***	–349***	–349***	–359***	–344***
	(52)[a]	(53)	(53)	(52)	(52)	(52)	(52)	(53)	(52)
β_P	Not applicable	–0.43	–0.58	–1.44**	–2.87***	–2.46***	–2.61***	–2.6**	–2.3**
		(0.48)	(0.49)	(0.66)	(0.85)	(0.88)	(0.91)	(1.1)	(1.1)
β_I	0.073	0.10	0.14	0.23*	0.37***	0.32**	0.34**	0.30**	0.24*
	(0.095)	(0.10)	(0.11)	(0.12)	(0.13)	(0.13)	(0.14)	(0.13)	(0.12)
β_T	0.119	0.09	0.06	–0.04	–0.17	–0.13	–0.14	–0.10	–0.05
	(0.095)	(0.10)	(0.11)	(0.12)	(0.13)	(0.13)	(0.13)	(0.13)	(0.12)
R^2	0.078	0.079	0.080	0.085	0.094	0.089	0.090	0.086	0.084
Number of observations	635	635	635	635	635	635	635	635	635

****, **, * Significantly different from zero at the 1%, 5%, and 10% level, based on a two-sided t test.*

[a] *Numbers within parentheses denote the standard deviations of the corresponding regression coefficients.*

Source: Vegetable Research and Information Center at the University of California's Cooperative Extension Service.

not warranted, because overall the yields in the long-term checks had been higher than the yields of the non-check varieties. In other words, Grandillo et al. (1999) show that the long-term checks had higher yields than the non-check varieties, but that the yield gap had been closing over time.

Given the limitations of the study by Grandillo et al. (1999), we obtained the authors' original tomato yield trial data from the Vegetable Research and Information Center at the University of California's Cooperative Extension Service and conducted an analysis as similar as possible to the one performed by the studies assessing genetic gains in wheat and corn. Unlike the wheat and corn data, however, the tomato data present difficulties in estimating genetic gains because of (a) non-simultaneous trials and (b) survivorship bias. The non-simultaneous trial problem arises because many of the varieties used in the trials changed from one year to the next, and there was not a single year when all varieties were tried simultaneously. The survivorship bias is associated with the fact that many of the varieties were only planted a few years, suggesting that they performed relatively poorly compared to other varieties planted over a larger number of years.

To control for non-simultaneous trials, we fitted the following regression:

$$\begin{aligned} Yield_{Var,T} &= \beta_0 + \beta_I\ IntroductionYear_{Var} \\ &\quad + \beta_T\ T + error_{Var,T}\,, \end{aligned} \tag{1}$$

where $Yield_{Var,T}$ denotes the average yield of variety *Var* in trials conducted in year *T*, $IntroductionYear_{Var}$ is the year when variety *Var* was introduced in the market, $error_{Var,T}$ is a residual, and β's are parameters. Annual genetic gains are measured by coefficient β_I, whereas net gains in yields due to improvements in management practices, development of susceptibility to new diseases, and the like are given by coefficient β_T. Results for Regression 1 are reported in the second column of Table 2. The point estimate of the annual genetic gains is only 73 kg per hectare, which is not different from zero at standard significance levels.

To assess the impact of survivorship bias, we estimated Regression 2:

$$\begin{aligned} Yield_{Var,T} &= \beta_0 + \beta_P\ TrialPeriodX_{Var} \\ &\quad + \beta_I\ IntroductionYear_{Var} \\ &\quad + \beta_T\ T + error_{Var,T}\,, \end{aligned} \tag{2}$$

Regression 2 expands 1 by incorporating the additional explanatory dummy variable $TrialPeriodX_{Var}$, defined as 1 if the number of years elapsed between the first and last trials for variety *Var* is less than or equal to *X*, and zero otherwise. For example, trials for variety H9492 were conducted in years 1997, 1998, 1999, and 2001. Therefore, variety H9492 has $TrialPeriod4_{Var} = 0$ and $TrialPeriod5_{Var} = 1$. Succinctly, dummy variable $TrialPeriodX_{Var}$ identifies varieties that do not appear to be good enough to warrant additional trials beyond *X* years.

Table 3. Ordinary least squares regressions of yields for tomato varieties on year of variety introduction and years between first and last trials, for trials conducted in California between 1980 and 2008.

Regressions: (C) $Yield_{Var,T} = \beta_0 + \beta_I\ IntroductionYear_{Var} + error_{Var,T}$

(D) $Yield_{Var,T} = \beta_0 + \beta_P\ TrialPeriodX_{Var} + \beta_I\ IntroductionYear_{Var} + error_{Var,T}$

Coefficient	**Regression (C)**	**Regression (D), with *X* in *TrialPeriodX*$_{Var}$ as defined below**							
		***X* = 1**	***X* = 2**	***X* = 3**	***X* = 4**	***X* = 5**	***X* = 6**	***X* = 7**	***X* = 8**
β_0	–334***	–341***	–344***	–341***	–355***	–354***	–354***	–361***	–347***
	(52)[a]	(52)	(52)	(52)	(52)	(52)	(52)	(53)	(52)
β_P	Not applicable	–0.57	–0.71	–1.30**	–2.10***	–1.87***	–1.94***	–2.04***	–2.06**
		(0.45)	(0.43)	(0.52)	(0.63)	(0.64)	(0.66)	(0.79)	(0.84)
β_I	0.187***	0.191***	0.192***	0.191***	0.199***	0.198***	0.198***	0.201***	0.194***
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
R^2	0.076	0.078	0.079	0.085	0.092	0.088	0.088	0.085	0.084
Number of observations	635	635	635	635	635	635	635	635	635

****, **, * Significantly different from zero at the 1%, 5%, and 10% level, based on a two-sided t test.*

[a] Numbers within parentheses denote the standard deviations of the corresponding regression coefficients.

Source: Vegetable Research and Information Center at the University of California's Cooperative Extension Service.

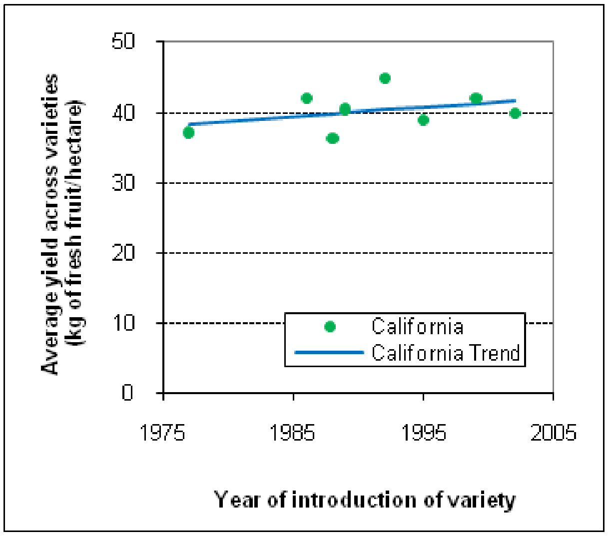

Figure 4. Average yields for tomato varieties introduced between 1977 and 2002 in the United States.

Source: Prepared from data supplied by the Vegetable Research and Information Center at the University of California's Cooperative Extension Service.

Results for Regression 2 corresponding to *X* = 1 through *X* = 8 are shown in columns three through ten of Table 2, respectively.

The results reported in Table 2 suggest that it is indeed important to account for survivorship bias, because $TrialPeriodX_{Var}$ has strong negative significance for $X \geq 3$. For example, all else equal, varieties characterized by four or fewer years between their first and last trials are estimated to yield 2,870 kg per hectare less than varieties having five or more years between their first and last trials (see seventh column of Table 2). More importantly, when controlling for survivorship bias with $X \geq 3$, annual genetic gains are significantly positive, with point estimates ranging between 230 and 370 kg per hectare.

The results shown in Table 2 are somewhat inconclusive regarding the relevance of controlling for non-simultaneous trials. This is because the magnitude of the coefficient corresponding to year of trial (*T*) is *economically* significant for $X \geq 4$, but it is not *statistically* significant. Negative values for β_T mean that successive trials with the same variety have lower yields (e.g., 170 fewer kg per hectare per year in the case of regressions including $TrialPeriod4_{Var}$), which could be due to the development of susceptibilities to plagues and diseases.

For completeness, Table 3 reports results of regressions without controlling for the non-simultaneous trials (i.e., regressions analogous to Regressions 1 and 2 above, but excluding explanatory variable *T*), and Figure 4 depicts the plot of average tomato yields versus year of introduction for the seven varieties for which trials were performed over at least six years. The estimated slope in Figure 4 is 135 kg per hectare per year, which is somewhat smaller than the coefficient estimates reported in Table 3. The slope in Figure 4 is different from the estimates in Table 3 because it is based on a smaller data set, and also because the regression for Figure 4 was performed using only the average yield for each variety across all trials, whereas the regressions reported in Table 3 were fitted using the original data (which contained a different number of trials for each variety).

Overall, it seems safe to conclude that annual genetic gains in tomato yields have been somewhere between 190 and 340 kg per hectare between 1977 and 1999. To put such gains in perspective, note that the average yield in the entire sample is 38,900 kg per hectare. Because tomato fruits have a substantial water content, typically ranging between 92.5% to 95% of the total fruit weight (Heuvelink, 2005), the gains in total tomato fruit weight per year exceed that of wheat and corn crops. However, when we translate the gain into dry matter assuming a 6.25% dry matter content in tomato fruits (the midpoint of the dry matter content reported by Heuvelink, 2005), the rate of gain falls to between 11.9 and 21.2 kg per hectare per year. This is lower than the rate of dry matter gain in wheat and corn we reported in the previous sections.

Hybrid vigor has been recognized in tomatoes since at least 1952 (Whaley, 1952). However, the technology was not accepted by processing tomato growers until 1971, and even then the rate of uptake was extremely slow. Orsetti (1980) describes the rate of adoption in the first eight years since introduction and provides reasons for the slow adoption. The main reason he gives for the slow rate of uptake is that producers did not anticipate sufficient yield increases to cover the substantially higher costs of those hybrid seeds.

The cost of hybrid tomato seeds is high because their production is very labor intensive and relatively difficult.[14] Male and female sources must be planted in separate areas of the field, and the female plants must be fertilized manually by shaking the male flowers to collect the pollen and fertilize the females by hand. In order to avoid self-fertilization, the females must be manually emasculated before the male pollen is introduced. This process must be repeated on a daily basis until the blooming cycle is completed. In 1980, this labor-intensive process resulted in costs for hybrids seeds that were five times greater than open-pollinated seeds (Orsetti, 1980). Currently, some companies produce hybrid tomato seeds in South America and the Far East to take advantage of the lower labor costs in those regions. Nonetheless, the price of hybrid tomato seeds is between three and ten times the price of seeds of open-pollinated varieties (Paul, 2004).

According to Orsetti (1980), the early varieties of hybrid tomato seed did not always provide large yield increases but did provide more consistent yields. In addition, hybridization allowed seed producers to more rapidly develop new varieties resistant to diseases and insects. Data provided in Grandillo et al. (1999) show the gradual adoption of hybrid varieties by the California processing sector in the period after that examined by Orsetti (1980). Market share of hybrid seeds rose from about 20% in 1980 to approximately 90% in 1990, and did not reach 100% until 1994.

Our discussions with industry experts and our review of the recent literature showed that while the private sector is responsible for almost all sales of tomato seeds, the private sector is not the primary producer of basic research to improve yields or enhance quality. Instead, public sector researchers in Florida, Israel, the Netherlands, California, and Wisconsin have developed and licensed some of the key commercial traits. These licenses are typically owned by quasi-private research foundations that act like the private sector when collecting returns on IP but retain some of the fees as a means to repay the public sector that funded the original research.

The relative lack of private sector basic research and the late adoption of hybrid tomatoes compared to hybrid corn poses a challenging question. Why didn't the private sector step in and dominate the hybrid tomato seed research as it has done for hybrid corn? One would imagine that the protection offered through the hybrid process would provide a sufficiently large IP incentive to encourage full private sector participation in all aspects of the research processes. Part of the answer is that this process is in fact ongoing. It has occurred at a slower pace in tomatoes because the crop is commercially less important than corn and because the hybrid varieties were discovered later and provided a relatively smaller yield advantage (after considering the substantially higher cost of hybrid tomato seeds) than in corn.

Another related explanation is that the effective strength of IP protection is weaker in tomato hybrids than in corn hybrids. Approximately half of the processed tomato acres in the United States are grown from transplants rather than seed. By raising plants up to a sapling stage in nurseries and then transplanting them into the field, growers can reduce the time needed to get a stand. Transplants are widely used because they stretch out the growing season, allowing the tomato processing factory to remain in production as long as possible during the season. However, this wide use of processed tomatoes grown from transplants may also

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[14] *A comprehensive description of the processes involved in the production hybrid tomato seeds is provided in Opeña, Chen, Kalb, and Hanson (2001).*

reduce the effective level of IP protection, because saplings may be obtained by asexual reproduction from high-value hybrid tomato plants, rather than from seeds.[15] Hence, it is possible for a tomato transplant to be a clone of a high-value hybrid plant, thus retaining all of its parent's vigor. The effective level of IP protection may be further reduced by the fact that most of the world's tomato acres are grown in places where US companies would find it difficult to protect against this kind of vegetative reproduction.

So, in essence, the tomato industry is itself a hybrid that combines private sector research with public sector research. Public sector research is still needed, as the private sector appears unwilling to incur the enormous costs of the research undertaken in the public sector because improvements might be copied. Importantly, the public sector is heavily reliant on IP itself, as much of the outcome of its research is licensed to the private seed sector. This system has led to substantial genetic gains in recent years.

Summary and Conclusions

In this article we describe three cases in an attempt to link private sector research incentives to resulting crop yield outcomes. This analysis is motivated by a recent theoretical paper by Lence, Hayes, McCunn, Smith, and Niebur (2005) that predicted that private sector IP incentives should be proportional to crop yield growth. In hindsight, the cases we chose were almost ideal for our purposes because the three crops provided a full range of IP protections within a single country.

Our analysis, coupled with industry interviews, suggests that IP protection in the US wheat market is weak because wheat growers are allowed to save seed and because the wheat breeder is responsible for the costs, both transactional and reputational, associated with enforcing those IP rights that do exist. IP protection in the processed tomato sector is higher than in wheat because all processing tomatoes are now hybrids. However, the possibility that protected tomato varieties could be asexually reproduced weakens IP and the incentive for the private sector to fund the basic research that might lead to high-value varieties. IP protection in the US corn market is strong, and as a result, the private sector dominates in all aspects of the research process.

With only three cases, we do not have enough data to prove any causal relationship between IP and yield growth or genetic gain. However, we can say that the yield and genetic gain data for these three crops are as predicted by the Lence et al. (2005) model. The greater the amount of effective IP (as measured by the ability of seed companies to profit from successful research), the greater the genetic gain.

We were concerned that the rate of yield growth in corn might be inherently greater than in tomatoes and wheat. Therefore, we compared IP protection in the EU wheat market with that in the United States. We discovered that IP protection for EU wheat seed companies is much stronger because farmers pay license fees to the breeder when they buy new seed and when they replant seed from the previous year. These fees are mandated by EU policy, and the breeder is not responsible for the transaction costs. EU wheat yields have grown at a rate similar to that of US corn yields.

The Lence et al. (2005) model and a paper by Alston et al. (2002) both predicted that the seed companies would not capture the full benefits associated with improved varieties. We were able to calculate the proportion of total benefits associated with corn rootworm control. These results suggest that the owner of the IP did obtain a very profitable return on the initial investment. The results also indicate that corn growers received an even greater return on the additional fees that they paid to the IP owner. These additional returns are greater than one might have anticipated because of the biofuel-driven increase in corn prices and the resulting need for the rotational flexibility associated with rootworm control.

We were not able to break out returns to IP investments in tomatoes because we could not find accurate data on hybrid seed costs. However, it is clear that yields in this sector have increased and that society as a whole has benefited from these yield increases. These yield increases have also helped the California tomato processing industry maintain its international competitiveness in this labor-intensive sector.

If our conclusions are correct, they suggest that the law of unintended consequences is alive and well. Rules that were put in place to protect US wheat growers may in the end have worked against their long-term interests. US wheat acres are down about 30% from the levels seen in the early 1980s, and part of this reduction may be explained by the competitiveness of high-yielding corn varieties that have successfully competed for land, despite what appear to be onerous seed corn costs.

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[15] *Tomato cuttings or sucker shoots can be easily rooted in water (e-mail communication from Dr. Gregory Welbaum, Professor of Horticulture at Virginia Polytechnic Institute and State University, dated November 30, 2007).*

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