Product Life Cycles and Innovation in the US Seed Corn Industry

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Abstract

The purpose of this study is to evaluate potential changes in the length of product life cycles in the US seed corn industry. We use the observed survival time on the market for hybrids sold during 1997-2009 to conduct a survival analysis. Our empirical results show that the average lifetimes of conventional and biotech corn hybrids have decreased over the last twelve years at similar rates and that the rate of decline in the life cycle length increased since 2004. We also find that the shorter product life cycles are closely linked to the accelerated levels of biotech product innovation in the US seed corn industry observed over the period of the analysis.

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1. *Introduction*

With the advent of agricultural biotechnologies, molecular genetics and recombinant DNA techniques have become essential components of US seed development programs and have accelerated the transfer of desirable traits into commercial seed germplasm. Along the way, the US seed corn industry has become more similar to other high-technology industries, which are characterized by large research and development (R&D) budgets, rapid innovation, and continuous product improvement.

Observers in technologically dynamic industries have regularly suggested that shrinking product life cycles go hand in hand with rapid product innovation. Yet, as we discuss in the next section, academic researchers have found limited empirical evidence to support such claims. In the US seed corn industry, Dooley and Kurtz (2001) recently proposed that the product life cycles (PLCs) have significantly declined and attributed these changes to the introduction of biotechnology, the commercialization of specialty corn varieties (e.g. waxy, white) and the use of various seed treatments. It is worth noting that empirical evidence of shrinking PLCs in the US seed corn market has not been provided by Dooley and Kurtz or by other previous studies. If true, however, this development would complicate the operations of seed companies and could have significant cost implications that extend well beyond the US seed corn industry.

Historically, the window during which seed companies are able to recover the fixed costs of breeding and biotech R&D has been fairly short for corn hybrids (Morris, Dreher, Ribaut, and Khairallah, 2003). Shorter PLCs would make the task of recovering past R&D expenditures (or funding future ones) more challenging. Shrinking hybrid PLCs would also complicate supply chain management and inventory control with parallel cost increases (Dooley and Kurtz). If the unit R&D expenses and the marketing, distribution, inventory, or obsolescence costs increased in the seed industry, farmers could face higher seed corn prices.

The purpose of this study is to address two key questions related to the duration of PLCs in the US seed corn industry. First, have PLCs in this industry been, in fact, growing shorter over time? Second, if the PLCs in the US seed corn industry have been growing shorter, what factors have been driving the change? We are specifically interested in the role of biotechnology innovation and in this context we analyze the life cycles of conventional and biotech hybrids over the 1997- 2009 period.

The paper is organized into six sections following this introduction. The next section reviews the existing literature on PLCs emphasizing studies of high-technology industries where the rate of innovation, product introduction, and product removal may be similar to the US seed corn industry. Section 3 discusses the underlying data used for the analysis. Sections 4 and 5 include the modeling approach and the empirical analysis of PLCs in the US seed corn industry. Section 6 examines the link between the evolution of PLCs and the flow of biotechnology product innovations in the US seed corn market. Finally, Section 7 presents conclusions and implications.

2. Review of the Product Life Cycle Literature

The study of PLCs has a long history in the economics and marketing literatures on consumer demand and product innovation, adoption and diffusion. The basic ideas underlying the PLC were originally derived from the biological life cycle and were adapted to describe the observed pattern of product sales between the introduction and removal of a product from the market. Although researchers have used different characterizations for the components of the PLC, most view the life cycle as having four distinct stages: introduction, growth, maturity, and decline. Early adopters buy the product in relatively low volume during the introduction stage, but sales increase rapidly during the growth stage as the early adopters become repeated buyers and information about the product diffuses in the marketplace. As new products become available to buyers and enter their own introduction phase, the mature product experiences a slow decline in sales. When the new products enter their growth phase, sales for the existing product decline at a more rapid rate and the product enters the decline phase. At some point, the diminished sales cannot support the costs of production (i.e., there are fixed costs or economies of scale), and the product is completely removed from the market. The adoption and diffusion of various product innovations have been thoroughly investigated in the economic literature, and Mahajan, Muller, and Bass (1990) provide a review.

Despite the extensive discussion of such product dynamics in the literature, there are only a few reliable empirical studies on the length of PLCs and a review of the early studies highlights some of the inherent empirical difficulties. Early studies reported by Young (1964) and Olshavsky (1980) showed evidence of shortening PLC length in different industrial goods, but these findings are not reliable because the data were not based on actual sales. Qualls, Olshavsky, and Michaels (1981) conducted a test of the hypothesis that the PLCs in consumer goods were getting shorter based on actual sales data. However, the authors recognized that some of the products under study were still on the market and this could bias their measurements of changes in the PLC length. To avoid this potential bias they restricted their analysis to the length of the introduction and growth stages of the PLC because all products in the study had completed these stages. They found that these PLC stages had grown shorter, but they also found considerable variations across individual products. Despite its data limitations, the results of this study have been widely cited as support for the claim that PLCs are getting shorter over time (Bayus, 1994).

Bayus (1998) analyzed the PLCs of desktop personal computer introductions and withdrawals between 1974 and 1992, and the data set included 2,800 models from 600 manufacturers. Bayus used the full lifetime for each observation and conducted an accelerated failure time (AFT) analysis that accounted for the presence of censored data. The author found evidence that the time to peak sales for these products had not been shrinking over time, but the length of the complete PLC had been declining. Further, his analysis showed that the outcome was not due to an acceleration of the introduction of product technologies. Rather, the apparent shortening of life cycles was driven by firms which entered the industry late and introduced models based on relatively old technologies. As a result, the PLCs for those late entrants were shorter than the lifetimes of incumbent models. Based on these results, Bayus (1998) concluded that the PLC in the computer industry was not systematically growing shorter.

Other studies have also looked beyond innovation to other factors that could influence the duration of PLCs. Greenstein and Wade (1998) investigated the PLCs in the computer mainframe industry for models introduced between 1968 and 1982. As in Bayus (1998), Greenstein and Wade tested the hypothesis that PLCs were getting shorter over time, and examined the conditioning impacts of market structure, product vintage, and firm effects. The authors discovered weak evidence regarding the impacts of industry and firm effects and they actually found some evidence that the PLCs had grown longer in their sample period.

Khessina and Carroll (2002) examined the length of PLCs in the optical disk industry over the period 1983-1999 and considered the conditioning effect of the type of firm offering new products in the market. The authors proposed that incumbent firms could have a competitive advantage relative to new startup firms and found that startups in this industry had higher withdrawal rates and shorter PLCs than firms with previous market experience.

In the case of the seed industry, there is only one study that has explored the duration of PLCs and relevant implications. Dooley and Kurtz (2001) did not measure the length of PLCs in the US corn seed market. Instead, they used anecdotal information from industry participants and proposed that between the mid-1990s and the early 2000s the average PLC in the US seed corn industry declined from 8 to 5 years. Taking these PLCs as given, Dooley and Kurtz focused their analysis on the potential cost implications of this decline. Using stochastic simulation they determined that shorter PLCs would more than double the inventory costs – a hefty increase since inventory costs can account for up to 40% of operating costs in the US seed corn industry (Akridge and Hychka).

3. Product Life Cycles in the US Seed Corn Industry: Underlying Data

One possible explanation for the complete scarcity of empirical evidence on the length of PLCs in the US seed corn industry is the demanding data requirements for such an assessment. Sales for all of the products offered in the market are required, typically, over a long period of time. In the case of the US seed corn industry this amounts to tracking thousands of hybrids sold every year, many of which have limited sales covering a few thousand acres.

Our study is enabled by a unique data set that has been collected by a commercial market research company – GFK Kynetec (previously Doane Marketing Research) through annual surveys of over 5,000 US corn farmers between 1997 and 2009. The complete data set is composed of more than 260,000 farmer responses. These responses are aggregated to form hybrid-specific observations. For each hybrid, the data set includes the name of the seed company marketing the hybrid, the maturity zones in which the hybrid is marketed,[1] the type of seed technology/trait (e.g., conventional, insect resistant, or herbicide tolerant hybrid), and the annual sales of the hybrid over its lifetime.

Because the farmer panel is large and it is selected every year to be representative of the US corn industry, the data set provides a nearly complete list of the hybrids sold in the market in any given year. The data set, however, is not without limitations. Some of the reported observations are incomplete and could not be used in our analysis. Specifically, all observations in which the hybrid name was not specified (e.g. the hybrid was characterized as "unknown" or "unspecified") or the sales information was incomplete were excluded from the final dataset used for our analysis. Due to these necessary adjustments in the data set, our analysis of PLCs covers the large majority of the hybrids marketed in the US over the 1997-2009 period, but not the whole population.

The data set also included a number of hybrids that appeared in the market for only one year. By consulting with individual seed companies we confirmed that in some instances the hybrids were actually sold for just one year. However, in most cases these hybrids had been sold for more than one year but were only captured once by the survey because they were sold in relatively small quantities. In the final data set used in the analysis one year hybrids were

[1] Maturity zones define the regional adaptation of hybrids to local weather and growing conditions. Corn hybrids require a specific accumulation of temperature to reach maturity. The required accumulation of temperature is usually expressed in terms growing degree days (GDDs). This rating is calculated using the maximum and minimum temperature of every day of the growing season so maturity zones usually spread across latitudes. Farmers would prefer to plant late corn hybrids because they usually produce higher yields, but late hybrids may not reach maturity until late in the season in cooler regions. Delaying harvest after grains reach physiological maturity exposes the corn to unnecessary risks (e.g. exposure to frost). For these reasons, growing zone considerations are important in determining the market fit of any hybrid.

excluded in order to avoid a downward bias in the estimated length of the average PLC in the US seed corn industry.

With the modified data set in hand, we can examine the evolution of PLCs in the US seed corn industry over the sample period. An immediate observation that emerges from the data is that there is significant variation in the observed product cycles of individual hybrids. For many hybrids the transition from introduction to growth, maturity and decline is gradual while for others it is abrupt or non-uniform. Figure 1 illustrates typical PLCs for specific hybrids introduced in the US market in 1999. Like those in Figure 1, most hybrids reach their maximum sales within 2 or 3 years from their introduction. Large acreage hybrids are typically sold and planted in multiple maturity zones and tend to have longer PLCs, in a few instances extending to 10 or more years. Smaller acreage hybrids tend to have more limited geographic scope and shorter PLCs.

[Figure 1 about here]

In order to estimate the length of PLCs of the various hybrids marketed in the US corn industry, survival or time failure analysis that allows for right censoring of observations is necessary. In evaluating PLCs, we must consider hybrids that have completed their cycles, like the ones in Figure 1, and others that are still actively marketed. The hybrids that have not completed their PLCs are right censored and if censoring is not taken into consideration, their life cycle would appear artificially shorter. The magnitude of this bias would be larger for more recent hybrids. For instance, the observed maximum PLC length of all hybrids introduced in 2008 would be two years while in reality a large share of the hybrids could ultimately remain on the market long after the last year in our sample period (2009).

It is important to note that all hybrids that were on the market during the first year of our sample (1997) could not be used for the calculation of PLCs because hybrids introduced in 1997 could not be distinguished from those introduced in prior years. Similarly, hybrids that were introduced in 2009 could not be used in the analysis since no survival information is yet available for this cohort. The final data set that is used for the statistical analysis of PLC duration in the US seed corn industry includes 7,941 hybrids, and nearly 21% (1,509) of these observations are right censored.

In addition to measuring the duration of PLCs, the impact of factors assumed to influence the dynamics of PLCs in the US corn seed industry can also be examined through survival analysis. One such factor of interest to this study is biotech product innovation. The period of our analysis spans the commercial life of corn biotechnology in its entirety. The first biotech corn hybrid that conferred resistance to European Corn Borer (ECB) was introduced in 1997. Since that time the industry has been the epicenter of biotech product innovation and has introduced a large number of biotech traits and events, more than in any other crop or national seed market in the world.

From our data it is easy to see the transformation of the US seed corn market that has occurred through biotech innovation between 1997 and 2009. Figure 2 depicts the market share of the technology types marketed over the sample period. Here, CONV identifies conventional hybrids that do not contain any biotechnology traits, HT represents herbicide tolerant hybrids, IR identifies insect resistant hybrids and STACKED represents hybrids that include two or more of the biotechnology traits/events.

[Figure 2 about here]

Following the introduction of biotech hybrids in 1997, the share of conventional seed corn hybrids has been gradually declining. While the market share of conventional hybrids stood at 95% in 1997, the share decreased to 10% in 2009. Insect resistant hybrids were the only biotech hybrids on the market in 1997 and had a market share of about 5% at that time. The market share of the IR hybrids increased steadily until 2005 and then declined in the following years. Note that this decline in the insect resistant market share does not mean that this trait began to disappear from the market after 2005. Rather, the insect resistance trait has been incorporated in the stacked corn hybrids, and nearly 53% of all stacked corn hybrids contained at least one insect resistance trait in 2009. The market share of herbicide tolerant hybrids also increased until 2005 but it has remained relatively stable since and stood at 21% in 2009. At the same time more than 75% of all stacked hybrids contained a herbicide tolerance trait in 2009. Given these differential rates of biotech product innovation in the US corn seed industry, we are interested to test whether conventional, herbicide tolerant, insect resistant and stacked corn hybrids experienced different PLC dynamics over the sample period.

3. Econometric Models and Estimation Methods

We can use survival or failure-time analysis to model the factors that influence the observed length of time seed corn hybrids remain on the market and estimate the length of PLCs. Let T represent the stochastic survival or failure time for a hybrid on the market, and the hazard function is

$$(1) \qquad \lambda(t;\mathbf{x}) = \lim_{h \downarrow 0} \frac{\mathrm{Prob}(t \le T < t+h \mid T \ge t, \mathbf{x})}{h}$$

which measures the marginal change in the probability that the duration ends in the near future conditional on the hybrid lasting to time t and on explanatory variables **x**. Under the accelerated failure time (AFT) model, $T = \exp(\mathbf{x}\boldsymbol{\beta})T_0$ where T_0 is the baseline survival time for a hybrid from the reference group with $\mathbf{x} = \mathbf{0}$. Accordingly, we have

(2) $$\ln(T) = \mathbf{x}\boldsymbol{\beta} + \varepsilon$$

where $\varepsilon \equiv \ln(T_0)$ is viewed as an error term. Under the assumption that $\varepsilon \sim N(0, \sigma^2)$, then T is a log-normal random variable, and the log-hazard function for the model is

(3) $$\ln(\lambda(t;\mathbf{x})) = \ln(\lambda_0(t\exp(-\mathbf{x}\boldsymbol{\beta}))) - \mathbf{x}\boldsymbol{\beta}$$

where λ_0 is the baseline hazard function. Alternatively, we may adopt other distributional assumptions for the model. For example, the Weibull distribution is a popular alternative to the log-normal specification, and it reduces to the proportional hazard model (Cox and Oakes, 1984) under restrictions on the scale parameter.

In contrast to the proportional hazard model, the AFT model is based on a direct link between the observed log-survival times and the explanatory variables (Swindell, 2009). From Equation (2), the slope parameters in $\boldsymbol{\beta}$ may be interpreted as semi-elasticities such that 100x $\boldsymbol{\beta}_j$ represents the approximate percentage change in the expected survival time given a unit increase in $\mathbf{x}_j$. The explanatory variables used in this analysis are defined in Table 1 and include the average planted acreage across the lifetime of the hybrid (AVGSIZE), dummy variables to account for the size of the seed firm marketing the hybrid (LARGE and MEDIUM), trait-specific dummy variables (CONV, IR, HT, STACKED), and dummy variables to indicate the largest maturity zone (region) in which each hybrid is sold (ZONE2 to ZONE11). Given that the hybrids were introduced in different years, we follow Wooldridge (2002) and Allison (2001) and include dummy variables to represent changes in the survival time associated with the year of introduction (INTRO1999 to INTRO2007). Accordingly, we can follow the approach taken by Bayus (1998) and use the estimated year-specific dummy coefficients to test for significant changes in the expected survival times across the different types of corn hybrids (CONV, IR, HT, STACKED) and over time.

4. Estimation Results

We first considered a pooled or restricted form of the AFT model for which the model parameters are the same across hybrid technology types. The maximum likelihood (ML) estimates of the model parameters were computed with the SAS LIFEREG procedure, which allows for right censoring of the survival data. For the pooled AFT model, we considered alternatives for the probability model before choosing a final specification. Although the generalized gamma model is very flexible and has a non-monotonic hazard function, the model has a large number of parameters and the computational algorithm for the ML estimator is subject to convergence problems (Allison, 2001). To choose the best fitting probability model from the remaining probability model alternatives, we analyzed the Cox-Snell residual plots (see Collett (2003) and Allison (2001)), which compare the model residuals to the fitted survival function. The diagnostic plot should follow a straight line if the estimated probability model provides good fit to the data, and we found that the log-normal model exhibited the best visual fit. Due to the limitation of model selection based on visual inspections, we also conducted likelihood-ratio (LR) tests for model specification under the alternative probability distributions, and the LR test results confirmed that the log-normal model has the best fit.

Then, we extended the AFT model to allow for technology-specific variation in the survival time of hybrids by including interaction terms between the technology dummy variables (CONV, IR, HT, and STACKED) and the year dummy variables (INTRO1999 to INTRO2007). Due to potentially harmful collinearity among these interaction variables, we estimated a separate version of the AFT model for each technology type, and the ML estimation results are presented in Tables 2-5.

We find that AVGSIZE coefficient is significantly positive in all four cases, and the estimates have very similar values. Given a unit (thousand acres) increase in AVGSIZE, we expect the survival time for all corn hybrids to increase by roughly 0.6%. Hybrids with broader market reach would tend to have long lifecycles. For instance, since the average hybrid in our sample seeds approximately 20,000 acres per year, a hybrid with twice that size would be expected to have a PLC roughly 12% longer than the average.

The estimated coefficients for LARGE and MEDIUM sized firms are also similar across the four models, and all estimates are significantly positive. Based on these values, we find that the expected survival time for all corn hybrids marketed by medium size firms is roughly 9% longer than those of smaller firms (which serve as baseline). Similarly, the expected survival time for all hybrids marketed by the top five firms is roughly 18% longer than that of hybrids marketed by small firms. Given that smaller seed firms cater to more regional markets and their hybrids tend to be planted on fewer acres, our results indicate that product turnover tends to be significantly higher among smaller seed companies.

There are also some differences in the average PLCs of hybrids marketed in different geographies. LR tests imply that that the maturity zone (region) variables are jointly significant in each model, but only the coefficient estimates for ZONE3 to ZONE8 are individually significant. Also, the magnitudes of these estimates imply that the expected survival times are roughly 7.1% to 12.6% shorter in these regions (relative to the base region, Zone 1). Since these zones cover key parts of the Corn Belt, it appears that seed firms develop new products at a higher rate for these key segments of the seed corn market.

Regarding the coefficients of primary interest in our survival study, the dummy variable parameters for the non-stacked technologies (CONV, IR, and HT) represent the overall differences in the survival times for the technology groups. We find that the estimated parameters are positive, which implies that the overall expected lengths of these PLCs are longer than the base group (stacked hybrids). Although there is some variation in these values across the four models, the results show that conventional corn hybrids are expected to have PLCs that are roughly 13-17% longer than for stacked hybrids. For the IR hybrids, the expected survival time is roughly 5-11% longer than for stacked hybrids, and the PLC length is expected to be about 6-15% longer for HT hybrids relative to stacked hybrids.

The dynamics in the PLC relationships are represented by the time-specific dummy variables, and almost all of the annual dummy coefficients are negative, which indicates that the expected lifetimes for all corn hybrids have generally decreased since 1998. Further, the four estimates that are statistically significant across all four models are the dummy coefficients for 2000 and 2005-2007. The decrease in average PLCs is relatively modest for 2000, and the estimated parameters imply that the expected survival times for hybrids introduced in 2000 are roughly 6.85% to 9.22% shorter than the survival times for hybrids introduced in 1998. In contrast, the reduction in hybrid lifetime accelerated after 2004. Indeed, the annual decrease in the expected survival times for hybrids introduced in 2005-2007 ranged from 15.7% to 25.6% relative to seed corn hybrids introduced in 1998, and the estimated decline in the expected hybrid lifetime was largest for 2006. Given that these annual dummy coefficients are not technology-specific and exhibit similar patterns across the four equations, they imply that this part of the decline in PLC length is a market-wide pattern.

The estimated dummy interaction coefficients allow us to evaluate the technology-specific changes in the PLC. For the CONV model in Table 2, the estimates become negative for 2003-2007, but only the estimate for 2007 is marginally significant. Thus, the decline in the survival times for conventional corn hybrids was not significantly faster than that of other hybrids. For the IR model in Table 3, the estimates become uniformly negative for 2005-2007, and the significance pattern is similar to the CONV case. However, the magnitudes of the estimates for 2005-2007 provide some evidence that the lifetimes for insect resistant hybrids decreased at a faster rate than other types of corn hybrids. The associated estimates for 2004-2007 in the HT model (Table 4) are positive but only marginally statistically significant, which implies that the herbicide tolerant hybrids may have had expected survival times extended than the other corn hybrids. However, the magnitudes of these dummy-interaction coefficients are relatively small, so there is a modest practical difference in the expected survival times of the HT hybrids. For the STACKED hybrid model (Table 5) the estimates are positive but statistically insignificant and hence no differences in the PLCs of stacked hybrids relative to all others were detected.

We may also illustrate the changes in hybrid PLCs across the trait categories by plotting their estimated expected lifetimes. The plots are presented in Figure 3 and they show that while there are variations, the expected hybrid lifetime across the different technologies is similar over the sample period. The average PLCs of conventional, IR and HT hybrids declined only slightly from 1998 to 2003. The decline was larger for stacked hybrids but by 2003 all hybrids had, more or less, the same expected lifetime.

[Figure 3 about here]

However, Figure 3 also shows that starting in 2004 the expected life cycle grew shorter for insect resistant, stacked and conventional hybrids and for herbicide tolerant hybrids the decline began in 2005. Although this analysis does not permit us to identify the exact cause of such variations in the life cycle of hybrids, we examine the link between biotech product innovation and PLC dynamics next.

5. The Link between Life Cycles and Biotech Product Innovation

To understand any potential relationship between the duration of PLCs and biotech innovation we examined in more detail the temporal patterns of biotech product introduction over the sample period. Table 6 lists all the biotechnology traits and products introduced in seed corn by year since 1997.

The data in Table 6 indicates that there were two separate waves of product introductions. During the first wave, a total of nine new biotech products were introduced between 1997 and 1999 (conferring combinations of ECB resistance and tolerance to IMI, Liberty and Roundup herbicides). No new products and traits were introduced until 2003 when a second wave of offerings started. From 2003 to 2007 a total of twenty four new biotech products were introduced in the US seed corn market and included new traits (Rootworm resistance), competing products for traits already in the market (Agrisure CB and GT, Herculex I), second generation traits (Roundup Ready II) and various combinations (Table 6).

Our results in the previous section indicate that the average duration of the PLCs of IR, HT and STACKED hybrids declined between 1998 and 1999 and stabilized or partially recovered in the following years until average PLC durations for all types of hybrids converged in 2003. Hence, the initial observed decline in the duration of the PLCs coincides with the first wave of biotech product offerings. The duration of PLCs for all four types of hybrids declined once more between 2004 and 2007 and the decline coincides with the second wave of biotech product innovation. Hence, there is evidence of a close link between biotech product innovation and the length of PLCs in the US seed corn industry. The timing and length of the decline in PLCs coincides with that of biotech product innovation and the rate of the decline increases with the rate of the innovation (number of new products per year placed in the market).

Faster biotech product innovation could lead to shorter hybrid PLCs in different ways. First, it could accelerate improvements in product performance (e.g. yield, cost efficiency) which, in turn, could imply higher rates of obsolescence and shorter PLCs for older hybrids. This would be akin to effects described in Dooley and Kurtz as "…technology is advancing so rapidly that new product releases are cannibalizing sales and shortening the life of other varieties in the market" (pp 3).

Second, faster biotech product innovation could lead to higher demand uncertainty, greater product turnover and, ultimately, shorter PLCs. Demand uncertainty is a constant in the seed corn industry (Jones, Lowe and Traub) but it is much higher for newer hybrids (Dooley and Kurtz). As the number of new traits and technologies increase, seed companies could offer a larger number of products in order to learn faster which combinations of traits and germplasm may best fit the needs of corn producers under varying insect and weed pressures across time and space (REF). Such portfolio experimentation could lead to shorter PLCs as unsuccessful products are culled by seed companies.

Third, an increase in the number of product offerings by seed companies would tend to increase the level of competition in the US seed corn industry (Alfranca and Lemarie). As a result, seed firms maybe more inclined to remove underperforming hybrids faster under competitive pressure. Based on our analysis, we cannot resolve whether it is through these or some other mechanisms that biotech product innovation has led to shorter product lifecycles in the US seed corn industry between 1997 and 2009.

6. *Summary and Conclusions*

Our analysis shows that between 1997 and 2009 the expected life cycles of seed corn hybrids have been similar for conventional and different types of biotech hybrids. The estimated PLCs show a gradual decline between 1998 and 2003 and a more abrupt decline since 2004. While other factors might have played a role, accelerated biotech product innovation seems to be a primary factor in the market-wide decline of PLC duration.

An important implication of our results is the potential impacts that the shorter PLCs could have on seed corn costs and prices. Because of the shorter PLCs, seed companies must incur additional expenses for supply chain management as the turnover of their product line increases. Furthermore, because of the increased demand uncertainty they must carry larger safety inventories to avoid stock-outs for the successful products and larger excess inventories for the unsuccessful ones, typically at significantly higher operating costs. As well, they will have less time to recover the R&D costs associated with developing new technologies.

These important changes could only lead to higher costs and, ultimately, higher seed prices. Indeed, higher rates of increases in seed corn prices have been observed since the mid-2000s and have been actively discussed in the farm press (e.g. Hillyer, 2005). What portion of such price increases are due to higher costs associated with shorter PLCs is not known.

The observed changes in the product lifecycles of the US seed corn industry in the last two decades suggest that understanding more fully the link between biotech product innovation and the dynamics of product life cycles in the seed industry is important. Dooley and Kurtz indicated that product life cycles in the US seed corn industry declined from an average of eight to five years between the mid1990s and 2000. While we cannot confirm the first figure we find that average PLC across all hybrids was a bit less than five years in 2000 and has declined significantly since. These results suggest that it is possible PLCs in the US seed corn industry could have been cut by more than half in a span of just over a decade. This could be a remarkable development for an industry that carries thousands of products in any given year and requires multiyear R&D, planning and production product cycles.

Given the observed levels of adoption of new biotech products by US corn farmers in recent years, it would appear that the value of productivity gains from biotech innovation is sufficiently large to compensate for the seed price increases. Accordingly, increased expenditures associated with shorter PLCs could be regarded as part of the cost of biotech innovation. Even so,

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Table 1. Definition of Explanatory Variables

Explanatory variables	Description
AvgSize	Average quantity sold of each hybrid over its entire life time
Medium	Dummy variable that equals one if the firm is medium sized and is ranked among firms 6-55 by market share
Large	Dummy variable that equals one if the firm is large and is ranked among the top 5 firms by market share
INTRO1999 to INTRO2007	Year dummy variables that equal one for years 1999 to 2007. The reference year is 1998.
ZONE2 to ZONE11	Regional dummy variables that equal one for the crop reporting zone in which most of the hybrid sales are located.
CONV*Year dummies	Interaction term between the type of trait and the year dummies

Table 2. ML Estimates of the AFT Model for Conventional Hybrids

Parameter	DF	Estimate	Std Error	Chi-Square	Pr > ChiSq
Intercept	1	1.1929	0.0598	397.48	<.0001
Avgsize	1	0.0057	0.0003	456.93	<.0001
Medium	1	0.086	0.0159	29.09	<.0001
Large	1	0.18	0.0192	87.74	<.0001
CONV	1	0.1771	0.0485	13.35	0.0003
HT	1	0.1261	0.0179	49.45	<.0001
IR	1	0.0876	0.0203	18.54	<.0001
Intro1999	1	-0.1034	0.0517	4	0.0456
Intro2000	1	-0.0898	0.051	3.1	0.0781
Intro2001	1	-0.0766	0.0487	2.47	0.1157
Intro2002	1	-0.0809	0.0497	2.65	0.1036
Intro2003	1	0.0005	0.0479	0	0.9909
Intro2004	1	-0.0421	0.0471	0.8	0.3713
Intro2005	1	-0.1631	0.045	13.15	0.0003
Intro2006	1	-0.2122	0.0458	21.5	<.0001
Intro2007	1	-0.1695	0.0459	13.62	0.0002
CONV*Intro1999	1	0.0979	0.059	2.75	0.0973
CONV*Intro2000	1	0.0182	0.0601	0.09	0.7627
CONV*Intro2001	1	0.071	0.0556	1.63	0.2019
CONV*Intro2002	1	0.0717	0.0575	1.56	0.2119
CONV*Intro2003	1	-0.0594	0.0596	0.99	0.3191
CONV*Intro2004	1	-0.0852	0.0612	1.94	0.1637
CONV*Intro2005	1	-0.0401	0.0571	0.49	0.4818
CONV*Intro2006	1	-0.0809	0.0603	1.8	0.1798
CONV*Intro2007	1	-0.1084	0.065	2.78	0.0955
Zone2	1	-0.0226	0.0426	0.28	0.5969
Zone3	1	-0.085	0.0402	4.48	0.0343
Zone4	1	-0.1049	0.0389	7.29	0.007
Zone5	1	-0.12	0.0386	9.65	0.0019
Zone6	1	-0.0764	0.0376	4.13	0.042
Zone7	1	-0.1101	0.0381	8.35	0.0039
Zone8	1	-0.0859	0.0389	4.88	0.0272
Zone9	1	-0.0627	0.0404	2.41	0.1208
Zone10	1	-0.0135	0.0545	0.06	0.8042
Zone11	1	-0.0245	0.0466	0.28	0.5989
Scale	1	0.456	0.0042		
Log Likelihood		- 5283.1936			

Table 3. ML Estimates of the AFT Model for Insect Resistant Hybrids

Parameter	DF	Estimate	Std Error	Chi-Square	Pr > ChiSq
Intercept	1	1.2092	0.046	691.54	<.0001
Avgsize	1	0.0057	0.0003	448.22	<.0001
Medium	1	0.085	0.016	28.33	<.0001
Large	1	0.1727	0.0192	80.98	<.0001
CONV	1	0.1673	0.0175	91.21	<.0001
HT	1	0.1127	0.0175	41.43	<.0001
IR	1	0.1139	0.0775	2.16	0.1414
Intro1999	1	-0.0294	0.0261	1.27	0.2596
Intro2000	1	-0.0922	0.0281	10.73	0.0011
Intro2001	1	-0.0343	0.0243	1.99	0.1584
Intro2002	1	-0.0363	0.0258	1.97	0.1601
Intro2003	1	-0.04	0.0283	2	0.1575
Intro2004	1	-0.0714	0.0286	6.25	0.0124
Intro2005	1	-0.157	0.0256	37.67	<.0001
Intro2006	1	-0.2254	0.0264	73.04	<.0001
Intro2007	1	-0.1797	0.0268	45	<.0001
IR*Intro1999	1	-0.0615	0.0899	0.47	0.4938
IR*Intro2000	1	0.0463	0.091	0.26	0.6107
IR*Intro2001	1	0.0134	0.0904	0.02	0.8818
IR*Intro2002	1	-0.0309	0.0922	0.11	0.7372
IR*Intro2003	1	0.0402	0.0883	0.21	0.6489
IR*Intro2004	1	-0.0201	0.0888	0.05	0.8209
IR*Intro2005	1	-0.1324	0.0855	2.4	0.1217
IR*Intro2006	1	-0.0891	0.091	0.96	0.3274
IR*Intro2007	1	-0.2137	0.1066	4.02	0.0451
Zone2	1	-0.0302	0.0426	0.5	0.4788
Zone3	1	-0.0901	0.0402	5.04	0.0248
Zone4	1	-0.1094	0.0389	7.92	0.0049
Zone5	1	-0.1265	0.0386	10.74	0.001
Zone6	1	-0.0821	0.0375	4.79	0.0286
Zone7	1	-0.1139	0.0381	8.95	0.0028
Zone8	1	-0.0894	0.0389	5.28	0.0215
Zone9	1	-0.0655	0.0404	2.62	0.1052
Zone10	1	-0.0252	0.0545	0.21	0.6437
Zone11	1	-0.0214	0.0467	0.21	0.647
Scale	1	0.4565	0.0042		
Log Likelihood		- 5289.3028			

Table 4. ML Estimates of the AFT Model for Herbicide Tolerant Hybrids

Parameter	DF	Estimate	Std Error	Chi-Square	Pr > ChiSq
Intercept	1	1.2391	0.0463	716.07	<.0001
Avgsize	1	0.0056	0.0003	445.87	<.0001
Medium	1	0.0859	0.0159	29.02	<.0001
Large	1	0.1749	0.0192	83.25	<.0001
CONV	1	0.1299	0.018	51.98	<.0001
HT	1	0.0626	0.0563	1.24	0.2656
IR	1	0.0481	0.0201	5.71	0.0169
Intro1999	1	-0.0255	0.0264	0.93	0.3338
Intro2000	1	-0.0685	0.0287	5.72	0.0168
Intro2001	1	-0.0165	0.0251	0.43	0.5114
Intro2002	1	-0.0301	0.0269	1.25	0.2632
Intro2003	1	-0.0297	0.0286	1.08	0.2987
Intro2004	1	-0.106	0.0294	13.04	0.0003
Intro2005	1	-0.2254	0.0268	70.88	<.0001
Intro2006	1	-0.2556	0.0279	84.21	<.0001
Intro2007	1	-0.2376	0.0289	67.51	<.0001
HT*Intro1999	1	-0.0884	0.0751	1.39	0.2391
HT*Intro2000	1	-0.0598	0.0731	0.67	0.4128
HT*Intro2001	1	-0.1052	0.0682	2.38	0.1231
HT*Intro2002	1	-0.0381	0.0683	0.31	0.5766
HT*Intro2003	1	-0.0076	0.072	0.01	0.9157
HT*Intro2004	1	0.1154	0.07	2.72	0.0992
HT*Intro2005	1	0.1486	0.064	5.39	0.0202
HT*Intro2006	1	0.0244	0.0664	0.13	0.7133
HT*Intro2007	1	0.1237	0.0672	3.39	0.0654
Zone2	1	-0.0212	0.0427	0.25	0.6193
Zone3	1	-0.0835	0.0402	4.31	0.0378
Zone4	1	-0.1	0.0389	6.61	0.0101
Zone5	1	-0.1157	0.0387	8.95	0.0028
Zone6	1	-0.0718	0.0376	3.65	0.0562
Zone7	1	-0.1036	0.0381	7.38	0.0066
Zone8	1	-0.0795	0.039	4.16	0.0413
Zone9	1	-0.0545	0.0405	1.81	0.1785
Zone10	1	-0.0085	0.0546	0.02	0.8769
Zone11	1	-0.0192	0.0467	0.17	0.6809
Scale	1	0.4559	0.0041		
Log Likelihood		-5278.2302			

Table 5. ML Estimates of the AFT Model for Multiple-Trait (Stacked) Hybrids

Parameter	DF	Estimate	Std Error	Chi-Square	Pr > ChiSq
Intercept	1	1.1779	0.1909	38.07	<.0001
Avgsize	1	0.0057	0.0003	455.72	<.0001
Medium	1	0.0848	0.0160	28.20	<.0001
Large	1	0.1763	0.0192	84.42	<.0001
CONV	1	0.1969	0.1873	1.11	0.2931
HT	1	0.1515	0.1876	0.65	0.4193
IR	1	0.1074	0.1878	0.33	0.5675
Intro1999	1	-0.0301	0.0249	1.46	0.2261
Intro2000	1	-0.0754	0.0266	8.04	0.0046
Intro2001	1	-0.0266	0.0237	1.26	0.2626
Intro2002	1	-0.0297	0.0250	1.41	0.2343
Intro2003	1	-0.0324	0.0275	1.40	0.2375
Intro2004	1	-0.0704	0.0284	6.12	0.0133
Intro2005	1	-0.1759	0.0257	46.76	<.0001
Intro2006	1	-0.2726	0.0283	92.80	<.0001
Intro2007	1	-0.2091	0.0312	44.95	<.0001
STACKED*Intro1999	1	-0.2042	0.2199	0.86	0.3531
STACKED *Intro2000	1	-0.1105	0.2168	0.26	0.6103
STACKED *Intro2001	1	-0.0321	0.1963	0.03	0.8700
STACKED *Intro2002	1	-0.1511	0.2047	0.54	0.4604
STACKED *Intro2003	1	0.0695	0.1937	0.13	0.7198
STACKED *Intro2004	1	0.0273	0.1921	0.02	0.8870
STACKED *Intro2005	1	0.0258	0.1899	0.02	0.8918
STACKED *Intro2006	1	0.1112	0.1898	0.34	0.5579
STACKED *Intro2007	1	0.0606	0.1894	0.10	0.7488
Zone2	1	-0.0286	0.0426	0.45	0.5019
Zone3	1	-0.0880	0.0401	4.80	0.0284
Zone4	1	-0.1072	0.0388	7.61	0.0058
Zone5	1	-0.1256	0.0386	10.58	0.0011
Zone6	1	-0.0810	0.0375	4.66	0.0309
Zone7	1	-0.1126	0.0381	8.74	0.0031
Zone8	1	-0.0885	0.0389	5.18	0.0228
Zone9	1	-0.0669	0.0404	2.74	0.0978
Zone10	1	-0.0219	0.0545	0.16	0.6881
Zone11	1	-0.0260	0.0467	0.31	0.5769
Scale	1	0.4564	0.0042		
Log Likelihood		-5289.5025			

Table 6. Timeline of Biotechnology Traits Introduced in Seed Corn Hybrids

YEAR OF INTRODUCTION	PRODUCT	BIOTECH TRAIT	PRODUCT SUPPLIER
1997	YGCB	Corn borer resistant	Monsanto
1998	IMI	Herbicide tolerant imidazoline	BASF
1998	LL	Herbicide tolerant glufosinate	Bayer
1998	RR	Herbicide tolerant glyphosate	Monsanto
1998	SR	Sethoxydim resistant	BASF
1998	YGCB-IMI	Herbicide tolerant imidazoline - Corn borer resistant	BASF/Monsanto
1998	YGCB-LL	Herbicide tolerant glufosinate - Corn borer resistant	Bayer/Monsanto
1998	YGCB-RR	Herbicide tolerant glyphosate - Corn borer resistant	Monsanto
1999	YGCB-IMI-LL	Herbicide tolerant glufosinate/imidazoline - Corn borer resistant	BASF/Bayer/Monsanto
2000	IMI-LL	Herbicide tolerant imidazoline/glufosinate	Bayer/BASF
2001	RR2	Herbicide tolerant glyphosate	Monsanto
2003	Herculex I-LL	Herbicide tolerant glufosinate - Corn borer resistant	Bayer/Dow
2003	YGCB-RR2	Herbicide tolerant glyphosate - Corn borer resistant	Monsanto
2003	YGRW	Rootworm resistant	Monsanto
2004	YGPlus	Corn borer/Rootworm resistant	Monsanto
2004	YGRW-IMI	Herbicide tolerant imidazoline - Rootworm resistant	BASF/Monsanto
2004	YGRW-RR	Herbicide tolerant glyphosate - Rootworm resistant	Monsanto
2004	YGRW-RR2	Herbicide tolerant glyphosate - Rootworm resistant	Monsanto
2005	Agrisure CB-LL-GT	Herbicide tolerant glufosinate/glyphosate - Corn borer resistant	Bayer/Syngenta
2005	Agrisure GT	Herbicide tolerant glyphosate	Syngenta
2005	Herculex I-LL-IMI	Herbicide tolerant glufosinate/imidazoline - Corn borer resistant	BASF/Bayer/Dow
2005	Herculex I-LL-RR2	Herbicide tolerant glufosinate/glyphosate - Corn borer resistant	Bayer/Dow/Monsanto
2005	YGPlus-RR2	Herbicide tolerant glyphosate - Corn borer/Rootworm resistant	Monsanto
2006	HX RW-LL	Herbicide tolerant glufosinate - Rootworm resistant	Bayer/Dow
2006	HX RW-LL-RR2	Herbicide tolerant glufosinate/glyphosate - Rootworm resistant	Bayer/Dow/Monsanto
2006	HX XTRA-LL	Herbicide tolerant glufosinate - Corn borer/Rootworm resistant	Bayer/Dow
2006	HX XTRA-LL-RR2	Herbicide tolerant glufosinate/glyphosate - Corn borer/Rootworm resistant	Bayer/Dow/Monsanto
2006	YGCB-GT	Herbicide tolerant glyphosate - Corn borer resistant	Syngenta/Monsanto
2007	Agrisure CB-IMI-LL	Herbicide tolerant glufosinate/imidazoline - Corn borer resistant	BASF/Bayer/Syngenta
2007	Agrisure CB-LL	Herbicide tolerant glufosinate - Corn borer resistant	Bayer/Syngenta
2007	Agrisure CB-RW-LL	Herbicide tolerant glufosinate - Corn borer/Rootworm resistant	Bayer/Syngenta
2007	Agrisure RW	Rootworm resistant	Syngenta
2007	Agrisure RW-GT	Herbicide tolerant glyphosate - Rootworm resistant	Syngenta
2007	YGPlus-IMI	Herbicide tolerant imidazoline - Corn borer/Rootworm resistant	BASF/Monsanto
2007	YGVT RW-RR2	Herbicide tolerant glyphosate - Rootworm resistant	Monsanto
2007	YGVT3	Herbicide tolerant glyphosate - Corn borer/Rootworm resistant	Monsanto
2008	Agrisure 3000GT	Herbicide tolerant glufosinate/glyphosate - Corn borer/Rootworm resistant	Bayer/Syngenta
2009	YGVT3 Pro	Herbicide tolerant glyphosate - Corn borer/Rootworm resistant	Monsanto

Figure 1. Typical Product Life Cycles in the US Seed Corn Industry

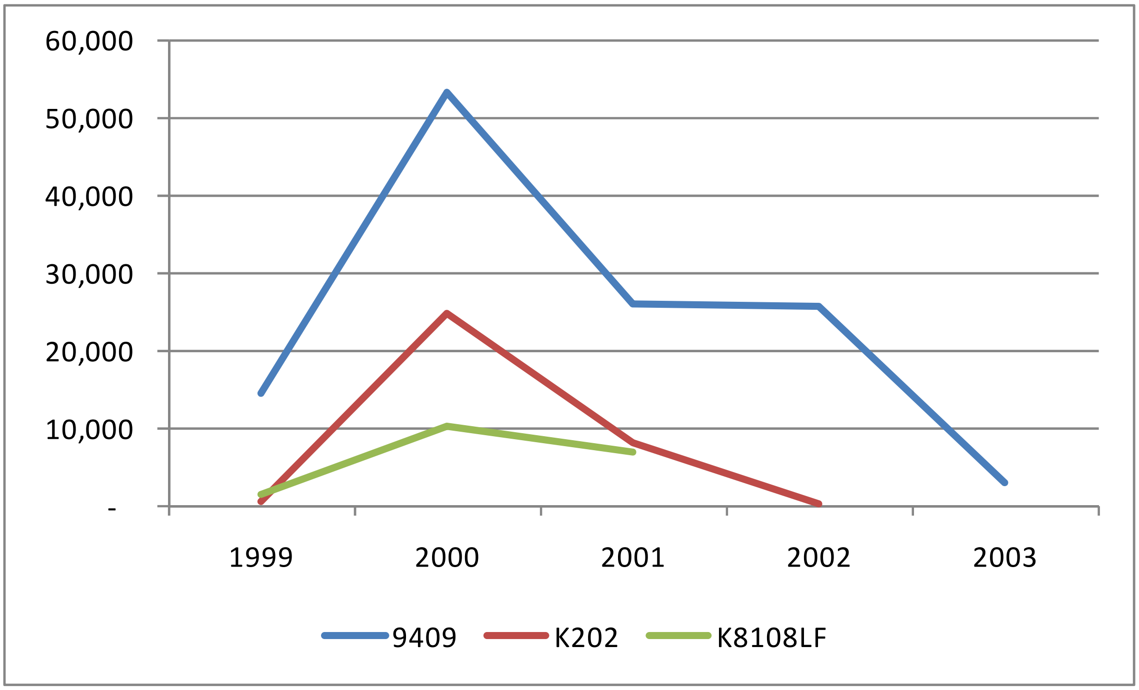

Figure 2. Market Share of Seed Corn Hybrids by Type and Year

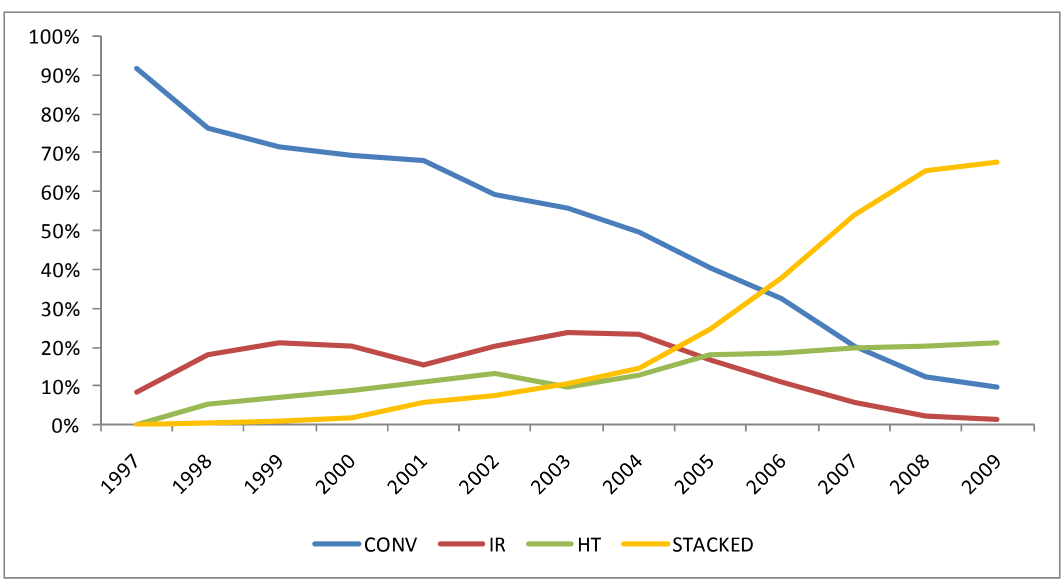

Figure 3. Estimated Average Survival Time by Hybrid Type and Year