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GM vs. Non-GM: A Survival Analysis of Hybrid Seed Corn in the US

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Abstract:

We investigate the survival of new seeds in the US hybrid corn seed market between 2002 and 2007. Controlling geographic location, we find that product characteristics and market structure variables have significant impacts on the hazard of corn hybrids. The results also suggest spill-over effects of learning among close substitute seeds, and a spatial pattern of survival: seeds in the center region of the Corn Belt survive longer in the market than those in the fringe region.

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1. Introduction

Product life cycle analysis is important to firms' research and development, marketing, and product portfolio investments. Hence, product survival can have an impact on the survival of firms themselves (e.g., Klepper, 1996; Agarwal and Gort, 2002). Indeed a firm's profitability is closely related to the performance of its products in the marketplace. Most of the existing literature on life cycle analysis focuses on survival at the firm level, such as firm's entry and/or exit decisions (e.g. Klepper and Simons, 2000; Fontana and Nesta, 2009; Nikolaeva et. al., 2009). In contrast, studies, especially the empirical ones, on product survival are limited. We identified four recent papers in the literature that examine the determinants of the product survival in different markets. These markets include the US mainframe computer market (Greenstein and Wade, 1998), the Swedish beer market (Asplund and Sandin, 1999), and the UK automobile market (Requena-Silvente and Walker, 2005; 2009).

Both Greenstein and Wade (1998) and Asplund and Sandin (1999) examine the impact of imperfect market competition on the life of a product. A firm that operates in a less competitive market may expect a longer product life because there are fewer alternative choices available to consumers compared to firms in a more competitive market. Using data from 1968 to 1982, Greenstein and Wade (1998) find that if the number of competing firms increases, the survival rate of commercial mainframe computers tends to decrease. However, Asplund and Sandin (1999) find that in the Swedish beer market from 1989 to 1995, products introduced by firms with higher market shares survive a shorter time. They argue that this may come from the cannibalization effect of these large firms.[1]

A product's survival in a market depends on its competitiveness against substitute

[1] For a multi-product firm, there may exist internal competitions among similar products manufactured by the firm itself, so-called "cannibalization effect" in the literature.

products both horizontally (e.g. in terms of differentiated tastes) and vertically (e.g. in terms of quality). Therefore the characteristics or attributes of the product play a critical role in driving the competition outcome. Requena-Silvente and Walker (2009) investigate the duration of differentiated products and focus on the quality and characteristics of the products with controls for market structure. In their application to the UK automobile market from 1971 to 2002, they find that the initial location in the product characteristic space and repositioning by introducing new variants, together with quality upgrading, significantly extend the life cycle of a car model.

Similar to Requena-Silvente and Waler (2009), our study also focuses on the survival of differentiated products: genetically modified (GM) and non-GM seeds. We analyze the US hybrid seed corn market, in which transitions from conventionally bred hybrids to the GM seeds have been widely observed in recent years. The US corn acreage planted with GM seeds has risen from 4 percent in 1996 to 85 percent in 2009 (USDA-NASS, 2009). To our knowledge, our study is the first application of survival analysis to the US seed market. Understanding of the survival cycle of different types of hybrids interfaces with various issues related to the adoption of the GM technology thus can be important to researchers and policymakers in this area.

We examine how the new biotechnology attributes of a GM seed affect its performance in the market under different market conditions. Moreover, we examine the potential impact of a seed company's vertical integration with the biotech sector, together with changing market structure, on seed survival. Firms with vertically integrated upstream/downstream sectors may have more flexibility in adjusting the position and quality of the final products compared to non-integrated firms. The corn hybrid seed market has become increasingly concentrated and vertically integrated with the upstream biotech sector. There are a total of over 200 seed companies operating in various local markets, however, only four firms are vertically integrated with the upstream biotech sector (Shi, Chavas, and Stiegert, 2010).[2] Seeds supplied by the four vertically integrated biotech-seed firms cover around 70 percent of the total corn acreage since 2005 (Stiegert, Shi and Chavas, 2010).

In this paper, we analyze the US hybrid seed corn market using data from 2000 to 2007 to explore the impact of technical and market factors that may influence the survival of various types of seeds. Since most firms carry more than one hybrid, it also allows for the examination of the potential cannibalization effect. Our analysis suggests that product characteristics such as the GM trait(s) embedded in seeds and factors related to market competition and vertical structure have significant effects on the survival of the corn seed. We find that GM seeds, both single-trait seeds and multiple-traits-stacked seeds, tend to survive longer than non-GM seeds in general. Moreover, market competition matters: An increased market share is associated with a lower hazard of product failure (i.e. a longer product life). We find evidence of information spill-over effects among GM seeds. We do not find strong evidence of the cannibalization effects, although there is some indirect evidence consistent with this hypothesis. Vertical structure also matters, such that hybrids supplied by a vertically integrated firm last longer than those by a non-integrated firm. We also find evidence of spatial differences: seeds developed and marketed in the center of the Corn Belt tend to survive longer than those in the fringe region.

The rest of the paper is organized as follows. Section 2 describes the US corn seed industry and the data. Section 3 discusses the econometric specifications. Sections 4 and 5 present the results and implications. Finally, section 6 concludes.

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[2] They are: Monsanto, Syngenta, DuPont, and Dow AgroScience. Another biotech company, Bayer CropScience, has entered the cotton seed market already, but has not (yet) entered the hybrid corn market during our study period.

2. The US corn seed market

Our analysis relies on a large, extensive data set on the US corn seed market collected by **dmr**kynetec [hereafter dmrk].[3] The dmrk data come from a stratified sample of US corn farmers surveyed annually from 2000 to 2007.[4] The survey provides farm-level information on corn seed purchases, corn acreage, hybrid identification number, biotech traits included in the hybrid, and seed brands. In total, the dmrk data contains 168,862 observations on individual corn seed purchases from 48 states.

The hybrid corn seed market is characterized by a large number of different hybrids present in the market with a fast turnover rate. Since the initial commercialization of GM seeds in 1996, US farmers have adopted this new technology rapidly. This transition is not only reflected in acreage of adoption as mentioned in section 1, but also in the increasing number of new hybrids introduced each year. Figure 1 shows the number of different hybrids and GM hybrids purchased by US farmers each year from 2001 to 2007 based on our data. The total number of different hybrids hovers around 3,600 between 2001 and 2004 and then increases steadily after that to 5,682 in 2007. Meanwhile, the number of different GM hybrids has been increasing dramatically over the years, from around 1000 in 2001 to over 4000 in 2007. Figure 2 illustrates the number of seed "entry" and "exit" each year, for all and for GM seeds only. A hybrid is defined as an "entry" for a given year if it never appears in the data in any earlier year and as an "exit" for a given year if it disappears in the data in any later years.[5] There are more "entry" seeds than "exit" seeds each year, and the overall trend is increasing for both events.

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[3] The firm **dmr**kynetec changed its name to GfK Kynetec in May 2009, web address: www.gfk.com. The seed data set is one of their products, called TraitTrak.

[4] Data prior to 2000 is not available from dmrk. The survey is stratified to over-sample producers with large acreage. The sampling weights are constructed using the farm census data.

[5] This definition may lead to an upward bias in the "exit" statistics at the end of the data period, and an upward bias in the "entry" statistics at the beginning of the data period due to lack of information before 2000 and after 2007.

Figure 1: Total Number of Corn Hybrids in US, 2001 – 2007

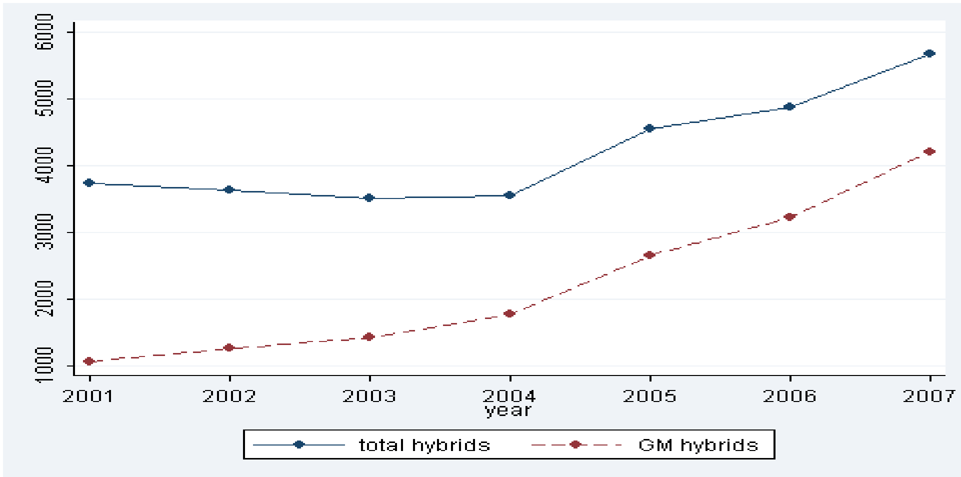
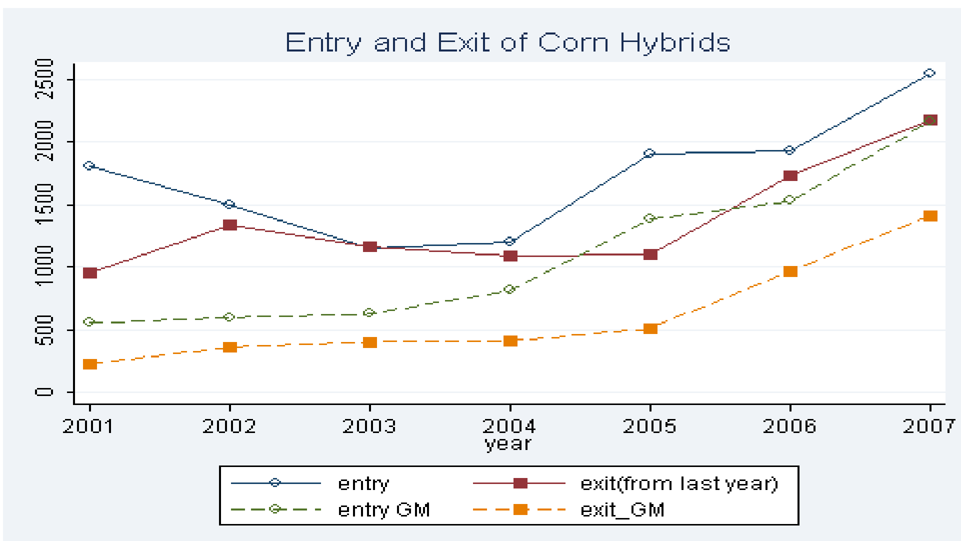


Figure 2: Entry and Exit of Corn Hybrid Seed in US, 2001 – 2007



The GM technology creates substantial product differentiation in seeds by empowering different functions via different biotech traits. Currently there are two major groups of genes/traits in the GM seed market: insect resistance designed to reduce yield damages caused by insects; and herbicide tolerance designed to reduce yield loss from competing plants (weeds). For corn, the insect resistance traits control damages caused by two groups of insects: the European corn borer (*ECB*) and rootworms (*RW*). The herbicide tolerance (*HT*) traits work with their corresponding herbicides. With *HT* seeds, farmers can apply the relevant herbicide to the field, which kills the weeds without damaging the crop. Single-trait biotech seeds contain only one of these traits, while the stacked biotech seeds contain multiple traits from some combination of these two groups of traits. In this paper, we categorize all the hybrids into eight groups: *Conventional*; *Single trait ECB*; *Single trait RW*; *Single trait HT*; *Stacked ECB_RW*; *Stacked ECB_HT*; *Stacked RW_HT*; and *Stacked ECB_RW_HT*. Note that *Stacked ECB_RW* refers to seeds that contain two traits, one *ECB* trait and one *RW* trait. Similar interpretation applies to the other stacking categories.

Some of the hybrids observed in 2000 have entered the market prior to 2000, thus create the left censoring problem. We focus on seeds that enter the market in and after 2002 and use the first two years data only to identify seed entry since 2002. Our data suggest that more than 80% of seed hybrids stay in the market for no more than three years. Therefore our treatment may help to bypass the left-censoring problem. Our final data set contains 10,245 hybrids from 46 states spanning from 2002 to 2007, of which 2,736 are conventional, 5,081 exited the market on or before 2007, and 5,164 are still present in the market in 2007.

3. The Model

We begin with a standard Cox Proportional Hazard model with time independent variables to estimate the survival of corn hybrids. The life span of a corn hybrid, denoted by *t*, is defined as the number of years that the seed is observed in the market. We assume that *t* is a realization of the random variable *T*, following the probability distribution function $F(t) = P(T \leq t)$. The survival function is then defined as $S(t) = 1 - F(t) = P(T > t)$, which measures the probability that a hybrid survives more than *t* years. The hazard function is

$$h(t) = \lim_{\Delta t \to \infty} \frac{P(t \le T < t + \Delta t \mid t \ge T)}{\Delta t}$$

which can be interpreted as the potential to exit given the hybrid has already survived *t* years. According to the standard Cox Proportional Hazard model, the hazard function is specified as

$$h(t, \mathbf{X_i}) = h_0(t)\exp\left(\boldsymbol{\beta}_\mathbf{i}\mathbf{X_i}\right), \tag{1}$$

where $h_0(t)$ is the baseline hazard, $\mathbf{X_i}$ is a vector of time independent explanatory variables.

We divide the explanatory variables in $\mathbf{X_i}$ into three groups: (I) the biotech characteristics of the seed; (II) market structure variables; and (III) other relevant covariates such as the geographic location. We will check whether these variables satisfy the time independent assumption or not.

In group (I), as discussed in section 2, the commonly observed GM traits in this market include insect resistance traits for controlling European corn borer (*ECB*), for controlling corn rootworms (*RW*), and various herbicide tolerance (*HT*) traits. We code these GM traits embedded in the corn hybrid, either individually or in a stacking system, as follows: If a corn hybrid contains any of the GM traits, the corresponding dummy variable (*ECB*, *RW*, or *HT*) is set equal to 1, otherwise zero. If the seed contains stacked traits, then in addition to the relevant individual dummies being set equal to 1, the corresponding stacking dummy such as *ECB_RW*, *ECB_HT*, *RW_HT*, or *ECB_RW_HT* is also set equal to 1. For example, for a single-trait *ECB* hybrid, the coding is *ECB* = 1 and other dummies are zero. For a double stacking hybrid with an *ECB* trait and a *RW* trait, the corresponding dummies are coded as *ECB* = 1, *RW* = 1, *ECB_RW* = 1, and other dummies are zero.

Market structure variables in group (II) include the state level market share of the company that sells the hybrid, the number of close substitute hybrids produced by the same company, the number of close substitute hybrids produced by other companies, the number of all GM hybrids produced by other companies, and a dummy variable for whether the firm that sells the hybrid is vertically integrated or not. All these market variables take the value during the year that the hybrid enters the market.

The market share variable is expected to capture the firm's market power position. The market share is defined at the state level because corn hybrids are often developed to fit local agro-climatic conditions such as soil type, rain fall, and sunlight. Therefore, a hybrid developed for Wisconsin is unlikely competing in the same market with a hybrid developed for California.

We use the number of GM hybrids produced by other companies and the number of close substitute hybrids produced by other companies to capture the external competition effects. We define close substitute hybrids as those hybrids in each of the eight seed categories: one conventional, 3 single-trait systems, three double stacked systems, and one triple stacked system. We also include the number of close substitute hybrids produced by the same company to capture the potential cannibalization effect. While similar hybrids produced by the same company may create internal competition, it is also possible that the increased number of similar hybrids can create positive information spillovers among farmers.[6] Moreover, all these variables are constructed by counting the corresponding number of hybrids at the national market. If these similar hybrids are designed for farmers in different regions, then the information spillover effect may dominate the internal and/or external competition effect.

Finally, we include a dummy variable of whether the seed company is vertically integrated with a biotech company or not. A vertically integrated firm may have an advantage

[6] For example, a firm carrying many hybrids in a given seed category may be viewed by farmers as having expertise in that particular technology.

over the non-integrated firms in access to the most advanced technology, which may affect the survival of the seed.

Variables in group (III) include geographic location variables. We construct the weighted latitude and longitude for a given hybrid using the planted acres of that hybrid in different regions over time. Thus the weighted variables reflect the primary region where the hybrid has been marketed. We allow for non-linear spatial pattern in our model by including both the linear and quadratic terms of the weighted latitude and longitude variables.

The standard Cox Proportional Hazard model imposes an implicit assumption that all explanatory variables are time independent such that the effects of these variables on the hazard are proportional over time. It follows that the hazard ratio between any two sets of these explanatory variables is constant over time. For example, suppose there are two sets of M predictors with the first variable different, $X_1 \neq X_1'$, then the hazard ratio is

$$HR = h_0(t)\exp\left(\beta_1 X_1 + \sum_{i=2}^{M} \beta_i X_i\right) \Big/ h_0(t)\exp\left(\beta_1 X_1' + \sum_{i=2}^{M} \beta_i X_i\right) = \exp\left(\beta_1 (X_1 - X_1')\right),$$

which is constant over time. This assumption appears rather strong, especially for the market structure variables.

To test whether this assumption holds for our explanatory variables, we perform a Goodness of Fit test based on Schoenfeld residuals (Schoenfeld, 1982). The null hypothesis is that the proportional hazard holds over time. Three market structure variables fail the test at 5% significance level: the market share of the company that sells the hybrid, the number of close substitute hybrids produced by the same company, and the number of GM hybrids produced by other seed companies. Following Kleinbaum and Klein (2005), we interact each of these variables with the logarithm of the survival time in order to capture the time-varying effects. Thus equation (1) is modified to an extended Cox model with the hazard function:

$$h(t, \mathbf{X}_i, \mathbf{X}_j(t)) = h_0(t)\exp\left(\boldsymbol{\beta}_i \mathbf{X}_i + \boldsymbol{\beta}_j(\log t \cdot \mathbf{X}_j)\right), \quad (2)$$

where $\mathbf{X}_j(t)$ contains the three covariates with time varying effects, and $\mathbf{X}_i$ include all the other covariates in group (I) – (III). Our analysis of corn hybrids survival relies on equation (2).

4. Results

Table 1 reports summary statistics of selected variables used in the analysis. For those seeds that enter the market on or after 2002 and exit the market on or before 2007, the mean survival time is 1.80 years for the conventional hybrids and 1.63 years for the GM hybrids. Note that for those seeds that still "survive" in the market, 79% are GM seeds. Thus, the 1.63 years of survival for GM hybrids is likely biased downward due to the right censoring. The average market share of seed companies is 4.5%, and it varies substantially across firms. Some companies may have a dominant share of 91.1% in a local (state) market, while others may have a negligible share of close to zero.

On average, when entering the market, each hybrid faces with about 1,215 close substitute hybrids and about 2,819 GM hybrids supplied by other companies, and about 17 close substitute hybrids by its own seed company. On average, about 9% of the number of different hybrids in each local market is supplied by vertically integrated firms. In some local markets the vertically integrated firms do not supply any seeds, while in some other local markets they supply all kinds of seeds. Finally, the weighted longitude and latitude information suggest that our study region is centered in Muscatine County, Iowa. The primary growing regions of hybrids in our sample range from Texas to North Dakota and from Maine to Washington.

Table 1. Summary statistics of selected variables

Variable		Number of observations	Mean	Standard Deviation	Minimum	Maximum
Hybrid survival[a] (years)	Conventional	2048	1.80	1.18	1	5
	GM	4963	1.63	1.02	1	5
Market share (%)		10245	4.5	9.2	1.77E-05	91.1
Number of close substitute hybrids by other companies		10245	1215	812	0	2820
Number of close substitute hybrids by own company		10245	17	24	1	193
Number of GM hybrids by other companies		10245	2819	1028	1302	4206
Vertically integrated		10245	0.09	0.28	0	1
Weighted longitude		10245	91.23	5.85	70.53	124.75
Weighted latitude		10245	41.53	2.47	27.60	48.77

[a] Note that in total there are 5081 hybrids that "fail" or exit the market in our sample, for which we could observe survival time. The rest 5164 hybrids still stay in the market by 2007 (thus "censored" in our analysis), of which 4096 are GM hybrids and 1068 are conventional.

Our extended Cox Proportional Hazard model in equation (2) is estimated by partial likelihood based on the observed order of exits (Kleinbaum and Klein 2005). The estimated likelihood and the coefficients are presented in table 2. Since the left-hand-side variable is the logarithm of the hazard, a negative coefficient means that if the value of the relevant explanatory variable increases, the hybrid will have a lower hazard to exit, i.e., will survive longer. We will discuss results reported in table 2 first, and then evaluate the marginal effects of the change in major explanatory variables on the hazard ratio in section 5.

Biotech Characteristics: In table 2, all coefficients of the individual biotech characteristics are negative, and statistically significant except for the *RW* trait and *ECB_RW* dummy. Given that the conventional seeds serve as the benchmark case, the results suggest that the incorporation of a GM trait into the seed reduces its hazard of exit in general except for the

Table 2: Results from the extended Cox model[a]

Dependent Var: *Log*(*hazard*)	Coefficient	*Z*-statistics
Group I: Biotech Characteristics, benchmark is conventional seeds		
ECB	-0.288***	-2.97
RW	-0.077	-0.56
HT	-0..391***	-4.56
ECB_RW	0.160	1.00
ECB_HT	0.374***	3.67
RW_HT	0.245*	1.61
ECB_RW_HT	-0.598**	-2.41
Group II: Market Structure Variables		
Market share, *Share*	-3.571***	-8.11
Number of close substitute hybrids by own company, *N_own*	-0.010***	-7.05
Number of close substitute hybrids by other companies, *N_others*	-1.28E-04***	-2.63
Number of GM hybrids by other companies, *N_GM_others*	-2.76E-04***	-14.45
Vertically integrated	-0.875***	-8.70
Group III: Other Covariates		
Weighted latitude	-0.217**	-2.41
Weighted latitude squared	0.003**	2.51
Weighted longitude	-0.259***	-8.43
Weighted longitude squared	0.001***	8.03
Time Varying Effects		
Share *log(*t*)	2.126***	4.83
*N_own**log(*t*)	0.003**	2.17
*N_GM_others**log(*t*)	-4.22E-04***	-7.52
Number of observations	10245	
Log Likelihood	-43657.28	

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

RW trait. Moreover, the coefficients of the double stacking dummies are all positive but less than the sum of the coefficients of corresponding individual trait in magnitude. This suggests that the double stacked GM hybrids also have a lower hazard than the conventional ones. However, the marginal contribution of each GM trait to the reduction in hazard is decreasing when multiple traits are stacked. The coefficient of the triple stacking dummy is negative and significant, suggesting an increasing marginal contribution of the individual GM traits to the further reduction in hazard when all three traits are stacked together.

The embedded GM traits increase product differentiation in the seed market, which may in turn increase the survival of the GM seeds. The rootworm trait (*RW*) has insignificant coefficient (negative), suggesting that seed with *RW* trait does not have an advantage over the conventional ones in terms of survival. Anecdotal evidence suggests that the rootworm trait technology has not gain as much success in the market as the corn borer trait technology, which may be reflected in the insignificant coefficients of *RW* and *ECB_RW*. In general, these results suggest that GM seeds survive (weakly) longer than the conventional hybrids. For an overall estimation of the effects of different GM stacking systems, we need to combine both the single trait effects and the stacking effects. The results will be reported and discussed in section 5.

Market Structure: For the market structure variables, the coefficient of the market share variable is negative and statistically significant. A higher market share is associated with a lower hazard of the hybrid, a result consistent with Greenstein and Wade (1998). However, the coefficient of the time interaction term is positive and significant, suggesting that this effect decreases over time.

In terms of competition effects, the coefficients of the number of close substitute hybrids by other companies and by the seed company itself, and of the number of GM hybrids by other companies are all negative and statistically significant. When the number of close substitute seeds in the market increases, either by other companies or by the seed company itself, the hazard of a seed exiting the market will decrease. This may suggest spill-over information learning or adoption effects within each group of hybrids. The more information farmers can gather about similar products (either via own experience or other's experience), the more likely the seed will stay as a viable choice to farmers. Moreover, the effect is decreasing over time for the number of seeds by the company itself, as indicated by the positive and significant coefficient of its interaction term with time. This may provide some indirect evidence of the cannibalization effect, which seem to counteract the learning effect when time goes by.

The number of GM hybrids produced by other firms is expected to capture competition effects among imperfect substitutes. The coefficient is negative and significant, so does the time interaction term. The more the GM hybrids in the market are during the year in which a hybrid enters the market, the lower the hazard of exiting the market that hybrid has, and the effect increases over time. This is contradictory to the competition effect hypothesis, where increased competition leads to faster product turnover. This may again suggest learning spillover effects among GM technology in general. And the effects are strengthened along with the flourishing of the GM technology.

Our results also indicate that the seed company's vertical integration with a biotech company helps reduce the hazard. Anecdotal evidence suggests that vertically integrated seed companies have access to better trait and seed germplasm compared to those seed companies operating under a license from the biotech company (Lauer, 2010). Shi and Chavas (2010) and Shi, Stiegert and Chavas (2010) examine the soybean and cotton seed markets, respectively, and found that for both soybean and cotton, seed prices under vertical integration tend to be higher than under licensing. If the higher prices reflect better quality associated with seeds supplied via vertically integrated channels, then such better quality seeds may survive longer as long as they provide greater net benefits (from increased farm productivity and reduced production cost) to farmers than those lower quality seeds.

Other Covariates: Spatial effects enter our model via linear and quadratic terms of the longitude and latitude of the primary planting region for a given hybrid. Since the early development of the hybrid technology in the 1930s, new hybrids have been developed and marketed to farms regionally (Griliches 1960). The introduction of GM technology has not changed the region-specific nature of seeds. The coefficients of the linear terms are negative while the quadratic terms are positive, all being significant at the 5% level. Hazard decreases from east to west and from south to north, and reaches a peak near the center (the Corn Belt), and then declines when moving further west and north. This finding suggests significant differences in seed survival between the central and fringe regions: corn seeds designed and marketed primarily for the Corn Belt survive longer than those for the fringe region.

5. Implications

To quantify the marginal effect of the main explanatory variables, we also simulate how changes in these explanatory variables would induce changes in the hazard ratio of a hybrid relative to the benchmark case: a conventional hybrid introduced by a non-vertically integrated seed company, with all other explanatory variables in groups (II) and (III) being set at the mean levels.[7] We calculate the hazard ratio, $HR = h(t, \tilde{\mathbf{X}}_{\mathrm{i}}, \tilde{\mathbf{X}}_{\mathrm{j}}(t)) / h(t, \mathbf{X}_{\mathrm{i}}, \mathbf{X}_{\mathrm{j}}(t))$, by adjusting the relevant dummy variable from 0 to 1, or by increasing the relevant continuous variable by one standard deviation from its mean. The results are reported in table 3.

The first seven rows in table 3 report the marginal effects of the biotech characteristics on the seed survival. All GM seeds have a hazard ratio less than 1, suggesting a lower hazard relative to the conventionally bred hybrids. However, the hazard ratios of seeds containing a *RW*

[7] If the variable is time dependent, we set the time index at $t = 2$.

trait, except for the triple stacking system, are not statistically different from 1, implying that their hazards of exiting the market are not different from that of the conventional seeds. This is again consistent with the anecdotal evidence of poor performance of *RW* trait in the market. The hazard ratio of a single trait *ECB* hybrid is 0.75, suggesting that inserting the single *ECB* trait to a conventional hybrid will decrease the hazard by 25%, *ceteris paribus* (i.e., 1 – 0.75 = 0.25). The hazard of a single trait *HT* hybrid is 32% less than that of the conventional seed (i.e., 1 – 0.68 = 0.32). Adding either the *ECB* trait or the *RW* trait on top of the *HT* trait actually increases the hazard relative to the conventional hybrid: a reduction of only 26% in hazard for the *ECB_HT* system, and no reduction for the *RW_HT* system, relative to the conventional seeds. The triple stacking system has the lowest hazard ratio (0.26), suggesting a 74% reduction in hazard relative to the conventional hybrid. Shi, Chavas and Stiegert (2010) find evidence of discount pricing in stacked traits in the US corn hybrid market, and the discount increases with the number of traits being stacked. This may help to explain the lowest hazard of the triple stacking system, suggesting that farmers share with the seed companies some of the benefits generated by the technology advancement in the triple stacked seeds.

For the market structure variables in group II, if the market share of the seed company during the entry year of the hybrid increases from the mean level (4.5%) by one standard deviation to 13.7%, the hazard of that hybrid in the later years will decrease by 18%, *ceteris paribus* (i.e., 1 – 0.82 = 0.18). An expanding market position may help the firm extend its product's life in the market. The increase in number of close substitute hybrids produced by the seed company itself also reduces the hazard. With an increase of one standard deviation, from 17 to 41, the relative hazard decreases by 17% (i.e., 1 – 0.83 = 0.17). Without the counteracting time effects, the reduction would be 22%.[8] If the number of close substitute hybrids produced by other companies increase from the mean level at 1,215 to 2,027, the hazard will decrease by 10% (i.e., 1 – 0.90 =0.10).[9] The number of GM hybrids produced by other companies has a strong effect on hybrid hazard: 44% reduction in hazard associated with 1,028 more GM hybrids produced by other companies in the market (i.e., 1 – 0.56 = 0.44). There seem to be strong spillover effects of learning or information among GM seeds in general.

Vertically integrated firms' seeds survive longer than non-integrated firms' hybrids: a 58% reduction in hazard relative to a non-integrated hybrid (i.e., 1 – 0.42 = 0.58). Major players in the market such as Monsanto, Syngenta, DuPont and Dow AgroScience, all being vertically integrated, seem to hold a competitive advantage over those smaller local seed companies.

For the location variables, we choose the benchmark location at the mean latitude and longitude, which is Muscatine County in Iowa. We simulated the hazard ratio when moving northeast (Osceola County, Michigan), northwest (Lake County, South Dakota), southeast (Ripley County, Indiana), and southwest (Dickinson County, Kansas) by changing one standard deviation in both longitude and latitude. Moving northeast and southeast will increase the hazard by 20% and 7%, respectively. Moving northwest does not change the hazard with statistical significance, while moving southwest will decrease the hazard by 6%. We also simulated how the hazard changes when moving north (Lacrosse County, Wisconsin), south (Lincoln County, Missouri), east (Noble County, Indiana) and west (Colfax County, Nebraska). The hazard increases when moving north (6%) or east (9%), and decreases when moving west (4%). The hazard does not change when moving south. These simulation results support the spatial pattern

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[8] When time goes by, the counteracting time effect will be higher: the hazard reduction will be 10% when $t = 5$ (the maximum survival time we can observe).

[9] One standard deviation for *N_others* is 812. Note that there are 8 hybrid groups and the number of seeds in each group varies substantially. Thus 812 here is a pooled statistics of both cross and within group variations.

Table 3: Marginal effects on the hazard ratio [a]

Variables		Estimated Coefficient	Benchmark scenario	New scenario	Hazard Ratio
Group I: Biotech Characteristics					
ECB		-0.288***	Conventional	Single *ECB*	0.75***
RW		-0.077	Conventional	Single *RW*	0.93
HT		-0..391***	Conventional	Single *HT*	0.68***
ECB_RW		0.160	Conventional	*ECB_RW*	0.81
ECB_HT		0.374***	Conventional	*ECB_HT*	0.74***
RW_HT		0.245*	Conventional	*RW_HT*	0.80
ECB_RW_HT		-0.598**	Conventional	*ECB_RW_HT*	0.26***
Group II: Market Structure					
Market share	*Share*	-3.571***	4.5%	13.7%	0.82***
	*Share*log(t)*	2.126***			
Number of close substitute hybrids by own company,	*N_own*	-0.010***	17	41	0.83***
	*N_own**log(*t*)	0.003**			
Number of close substitute hybrids by other companies		-1.28E-04***	1215	2027	0.90***
Number of GM hybrids by other companies,	*N_GM_others*	-2.76E-04***	2819	3847	0.56***
	*N_GM_others**log(*t*)	-4.22E-04***			
Vertically integrated		-0.875***	Non-integrated	Vertically integrated	0.42***
Group III: Other Covariates					
Latitude		Linear: -0.217**	Muscatine County, IA	NE: Osceola, MI	1.20***
		Quadratic: 0.003**		NW: Lake, SD	1.02
				SE: Ripley, IN	1.07***
				SW: Dickinson, KS	0.94***
Longitude		Linear: -0.259***		N: Lacrosse, WI	1.06***
		Quadratic: 0.001***		S: Lincoln, MO	0.98
				W: Colfax, NE	0.96**
				E: Noble, IN	1.09***

[a] Statistical significance is noted by * at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

that those seeds developed and marketed for the center region of the Corn Belt survive longer than those developed and sold in the fringe region. This may reflect firms' different strategies in setting up priority in developing and market seeds in the "major" markets such as those in the central Corn Belt and may leave behind the “niche” markets such as those in the fringe regions. Shi, Chavas and Stiegert (2010) and Stiegert, Shi and Chavas (2010) also find evidence of spatial differentiation in corn seed pricing, in which seeds are generally priced higher in the central Corn Belt region compared to those in the fringe region.

6. Conclusion

In this paper we investigate the determinants of the survival of new hybrids in the US seed industry from 2002 to 2007. We find that the new characteristics (the embedded GM traits) contribute towards the survival of a corn seed hybrid in general. Increased product differentiation through GM technology, either individually or stacked, tends to extend product life in the market. We also find that products from a firm with greater market share tend to enjoy longer life than those from firms with less share of the market. There is also evidence of positive spillover learning effects through information on firms’ similar seeds and other firms’ GM seeds including those similar ones. However, we can only infer at most indirect evidence for the cannibalization effects. Vertically integrated firms, all being the major players in the market, have an advantage in competing with other seed companies in terms of product survival. Finally, we also find evidence supporting the spatial pattern of seed survival: hybrids developed for the center Corn Belt region tend to survive longer than those for the fringe region.

Our results shed lights on the factors determining the seed survival in the US corn hybrid market. We find that the market structure factors play an important role in the seed turnover, and that seeds companies tends to treat geographic market segments differently. Our results can be used by a wide array of interested parties such as farmer groups, legal scholars, the U.S. Department of Agriculture, and the U.S. Department of Justice.

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