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A Hedonic Model of Corn Seed Prices

Jorge Fernandez-Cornejo jorgef@ers.usda.gov
Karen Valle
Economic Research Service, USDA

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Introduction

Modern agricultural biotechnology has facilitated the development of biological innovations embodied in new seeds, contributing to sustained agricultural productivity growth and helping ensure an abundance of food and fiber (Fernandez-Cornejo, 2004). Genetically engineered (GE) varieties with pest management traits became commercially available for major crops (corn, soybeans, and cotton) in 1996. More than 15 years later, adoption of these varieties by U.S. farmers is widespread and U.S. consumers eat many products derived from GE crops—including cornmeal, oils, and sugars—largely unaware that these products were derived from GE crops. A notable feature of the adoption of GE corn is the rapid growth in corn seed prices that accompanied the rapid increase in corn seed with multiple (stacked) GE traits. These seeds have often been shown to offer several advantages to farmers, particularly increased yields. This paper presents preliminary empirical results on the estimation of the pricing of seed traits for corn using 2010 data.

Adoption of GE Corn

U.S. farmers planted about 169 million acres of GE corn, soybeans, and cotton in 2013, mostly for herbicide tolerance (HT) and insect resistance (Bt), accounting for almost half of the estimated total land used to grow all U.S. crops (Fernandez-Cornejo et al, 2014). Growth of GE varieties for major crops has been rapid. Bt corn— commercially introduced to control the European corn borer in 1996, the corn rootworm in 2003, and the corn earworm in 2010—was planted on less than 2 percent of the corn acres in 1996, 19 percent in 2000, 35 percent in 2005, and 76 percent in 2013 (Figure 1). HT corn increased from 3 percent of corn acres in 1996 to 7 percent in 2000, 26 percent in 2005, and 85 percent in 2013.

Adoption rates of stacked-trait seed varieties have increased quickly (Fig 2). For example, stacked corn seeds with Bt and HT traits grew from 1 percent of the corn acres in 2000 to 9 percent in 2005 and 71 percent in 2013. This rapid growth is not surprising; an analysis of ARMS corn data indicates that stacked-trait seeds (seeds with several GE traits) have higher yields than conventional seeds or seeds with only one GE trait (Fernandez-Cornejo et al., 2014). For example, 2010 USDA survey data (ARMS) show that conventional corn seeds had an average yield of around 130 bushels per acre in 2010. By contrast, corn seed with two types of herbicide tolerance (glyphosate and glufosinate) and several types of insect resistance (corn borer, corn rootworm, and corn earworm) had an average yield of about 170 bushels per acre. These results are also consistent with findings by Nolan and Santos (2012), who analyzed a rich dataset from experimental hybrid trials collected by the extension services of 10 universities in major corn-producing States from 1997 to 2009.

Seed Prices

The market price of seed incorporates the costs associated with seed development, production, marketing, and distribution (Fernandez-Cornejo, 2004). The price must reflect farmers' willingness-to-pay while ensuring a profit margin after costs. Furthermore, the price depends on the competitiveness of the particular seed market, and the pricing behavior of those firms that hold large shares of the market (NRC, 2010). In recent decades, private sector R&D costs have been rising with the application of new technologies, and much of the increase in seed prices has been associated with this trend (Krull et al., 1998). R&D costs vary among the different seed markets. For example, the corn seed market depends extensively on private sector R&D and

passes these costs on to farmers. The wheat seed market depends largely on public sector research, which is largely cost free for farmers. There is no GE wheat commercially available.

The price of GE corn seeds grew by about 50 percent in real terms (adjusted for inflation) between 2001 and 2010 (Figure 3). The increase in GE corn seed prices can be attributed in part to increasing price premiums over conventional seeds (which include technical fees) associated with the rising share of GE seeds with more than one trait (stacked) and/or more than one mode of action for particular target pests (NRC, 2010). Another factor contributing to the increase in GE corn seed prices is the improvement in seed genetics (germplasm) (NRC, 2010). The rapid adoption of GE crops indicates that many farmers are willing to pay higher seed prices because of improved seed performance and the additional pest management traits embedded in GE seed. As indicated earlier, some empirical findings show that stacked trait seeds (seeds with several GE traits) have higher yields than conventional seeds or seeds with only one GE trait.

Various studies of stacked GE seed varieties have found subadditive pricing in stacked traits; that is, stacked seeds are priced less than the sum of their component values (Stiegert et al., 2010). Shi et al. (2008, 2010) note that sub-additive pricing is consistent with "the presence of economies of scope in seed production." Moreover, these scope economies are consistent with "synergies in R&D investment (treated as a fixed cost)" across stacked seeds that can contribute to reducing total cost (Shi et al., 2010).

Research Methodology

The objective of this study is to examine the pricing of genetically engineered (GE) traits in corn seeds. The hedonic approach uses a hedonic function, which entails expressing the price of seed as a function of their "quality characteristics" (Fernandez-Cornejo et al., 1995). The quality

characteristics considered in our hedonic functions are three insect resistance traits (Bt to control the European corn borer, corn rootworm, and corn earworm), GE herbicide tolerance traits (glyphosate, glufosinate), and a non-GE herbicide tolerance trait (IMI-corn). The conventional (non-GE) seed was considered as the base.

A seed hedonic function may be expressed as $P = W(\boldsymbol{D}, \boldsymbol{X})$, where P represents the price of seed (including "technical fees"), $\boldsymbol{D}$ is a vector of characteristics or quality variables and $\boldsymbol{X}$ is a vector of other variables. Many studies of hedonic functions use a generalized linear form, where the dependent variable and each of the continuous independent variables is represented by the Box-Cox transformation. This is a mathematical expression that assumes a different functional form depending on the transformation parameter, and which can assume both linear and logarithmic forms, as well as intermediate non-linear functional forms. In this preliminary study, we use a semi logarithmic function. Thus, using a semi log version of the hedonic equation proposed by Shi, Chavas, and Stiegert (2010), our hedonic function is:

$$log\ P = \alpha_0 + \sum_{i=1}^{6} \alpha_i D_i + \sum_{j=i+1}^{6} . \sum_{i=2}^{6} \alpha_{ij} D_{ij} + \sum_{z=j+1}^{6} . \sum_{j=i+1}^{6} . \sum_{i=2}^{6} \alpha_{ijz} D_{ijz}$$

$$+ \sum_{r=z+1}^{6} . \sum_{z=j+1}^{6} . \sum_{j=i+1}^{6} \sum_{i=2}^{6} . \alpha_{ijzr} D_{ijzr} + \sum_{t=r+1}^{6} . \sum_{r=z+1}^{6} . \sum_{z=j+1}^{6} \sum_{j=i+1}^{6} . \sum_{i=2}^{6} . \alpha_{ijzrt} D_{ijzrs}$$

$$+ \phi \boldsymbol{X} + \varepsilon$$

In this equation, *log* represents the natural logarithm, *P* is the seed price (which includes the "technology fee"), $\boldsymbol{X}$ is a vector of other variables, D_1 is a dummy variable for conventional, non-GE, corn seed variety; D_2 is a dummy for a corn seed variety with a Bt trait to control the European corn borer; D_3 is a dummy for a corn seed variety with a Bt trait to control the corn rootworm; D_4 is a dummy for a corn seed variety with a Bt trait to control the corn earworm; D_5 is

a dummy for a corn seed variety GE with a herbicide tolerance trait ; and D_6 is a dummy for a corn seed variety with a herbicide tolerance trait obtained by non-GE means. D_i is equal to one if the corn seed has the particular trait (individually or stacked) and zero otherwise. D_{ij} is a dummy variable for double stacking of two traits (*i* and *j*); D_{ijz} , D_{ijzr} , D_{ijzrt} are dummy variables for triple, quadruple, and quintuple-stacking, respectively. For conventional and single trait seeds the dummies D_{ijz} , D_{ijzr} , D_{ijzrt} are each equal to 0. It should also be noted that not all seed types were reported to be sold. Thus, not all possible dummies in the hedonic function shown above exist. For example, the corn seed variety with a Bt trait to control the corn earworm was not sold as a single trait version or as a double-stacked version (to our knowledge; table 1). α_i , α_{ij}, α_{ijz}, α_{ijzr}, and α_{ijzrt} are coefficients in the estimation, and ε is a stochastic disturbance. To avoid perfect collinearity, we set $\alpha_1 = 0$, which implies that we take conventional seed as the base. As Shi, Chavas, and Stiegert (2010) observe, in the absence of stacking $\sum_{i=1}^{J} D_i = 1$, but with stacking $\sum_{i=1}^{J} D_i \geq 1$ because seeds include the genetic traits of more than one type. Shi, Chavas, and Stiegert (2010) also note that the special case that $\alpha_{ij} = \alpha_{ijz} = \alpha_{ijzr} = \alpha_{ijzrt} = 0$ corresponds to standard component pricing. When these parameters are not all negative, the hedonic function above allows for nonlinear pricing associated with stacking. Negative parameters are a reflection of "sub-additive bundle pricing," meaning that stacked seeds are priced less than the sum of their component values, and positive parameters reflect "super-additive bundle pricing."

Given the semi-log nature of our hedonic function, these α coefficients of the seed-type dummy variables may be interpreted as the log of the seed price ratios (relative to the price of the conventional varieties); that is, $log\ (P_i/P_1)$, holding the other variables constant. Therefore, the ratio of the seed price with given GE trait(s) relative to the conventional seed price is $P_i/P_1 = \exp(\alpha_i)$.

The vector of other explanatory variables $\boldsymbol{X}$ includes state dummies to "capture spatial heterogeneity in cropping systems and state level institutions such as the effectiveness of the state extension systems" (Shi et al., 2009). In addition, for each farm observed, we include deviations from the minimum longitude and deviations from the minimum latitude. According to Shi, Chavas, and Stiegert (2010), taking into account longitude and latitude "control[s] for possible pricing differences associated with spatial heterogeneity in farming systems." Latitude influences solar radiation available for plant growth and longitude captures the general rainfall gradient that occurs when moving from east to west in the U.S.A. (Mitchell et al., 2009). To allow for nonlinearities in location we also include the squares of longitude deviation and latitude deviation. Other variables included are corn acreage and seeding rate. Farm-level corn acreage is included because it "captures possible price impacts associated with farm size" (Shi, Chavas and Stiegert, 2010). A variable for seeding rate is also included but, as discussed below, we include the predicted value of seeding rate since this variable is not exogenous (e.g., it is influenced by seed price).

The hedonic function is estimated using 2010 ARMS data for corn. The Agricultural Resource Management Survey (ARMS), sponsored by USDA's National Agricultural Statistical Service (NASS) and the Economic Research Service (ERS), has a multi-phase, multi-frame, stratified, probability-weighted design. In other words, farmers with pre-selected characteristics are administered the ARMS survey each year. After data collection, NASS generates probability weights to help ensure that the ARMS sample accurately represents the population of U.S. farms. After excluding observations with missing values there were 1,385 observations available for the econometric estimation.

Estimation

Ordinary least squares (OLS) estimates are biased and inconsistent when current period endogenous variables appear as regressors in other equations in the system (SAS, 2014). The SYSLIN procedure from SAS provides several techniques that produce consistent and asymptotically efficient estimates for systems of regression equations.

We use the two-stage least squares estimation using the 2SLS option of the SYSLIN procedure from SAS. We consider the seeding rate as endogenous. The 2SLS results are based on predicted values for this endogenous regressor from the first stage instrumental regression.

Preliminary Results

Table 1 presents the sample weighted means and brief definitions of the more important variables. For example, the sample mean of the corn seed price in 2010 was $205 per bag (a bag contains 80,000 kernels) and the seeding rate was 20 pounds of seed per acre, which is approximately equivalent to 29,500 seeds per acre. Nine percent of the seed was conventional (without any pest management trait). The seed type most used (27 percent) was the triple-stacked variety, genetically engineered with two types of insect resistance (to control the European corn borer and the corn rootworm) plus an herbicide tolerance trait.

Table 2 shows the sample seed price by type. The lowest priced seed type was conventional seed at $149 per bag, followed by the non-GE herbicide tolerant corn seed (such as IMI corn, tolerant to the imidazolinone family of herbicides) at $160 per bag. All the GE seeds had higher prices, ranging from seed with GE herbicide tolerant traits at $183 per bag to the seed with a Bt trait to control the corn rootworm at $216 per bag. The price of all the seeds with Bt traits was above $205 per bag. The most expensive was seed with multiple traits (four or more)

at $248 per bag followed by seed with triple stacked Bt traits to control the European corn borer, the corn rootworm and the corn earworm at $243 per bag.

Table 3 shows the preliminary regression results for the hedonic function estimated using two-stage least squares and Table 4 presents the calculated results of the seed premium relative to the conventional seed calculated from the regression estimates. For example, the estimated price premium for Bt corn seed with a trait to control the European corn borer over conventional seed is $55 per bag (table 4), while the estimated price premium for Bt corn seed with a trait to control the corn rootworm is $68 per bag and the estimated price premium for corn seed with GE a herbicide tolerance trait is $36 per bag. The estimated price premium for corn seed with a non-GE herbicide tolerance trait is $11 per bag.

Focusing on the coefficients of the stacked trait seed types, we note first that in the case of double-stacking of Bt traits to control the European corn borer (ECB) and the corn rootworm (CRW), the coefficient was negative and statistically significant, indicating sub-additive pricing. Similar results and conclusion can be reached for the cases of the double-stacked seed with Bt to control the ECB and with herbicide tolerance trait (BTECB_HTGE) as well as for double-stacked seed with Bt to control the CRW and with a herbicide tolerance trait (BTCRW_HTGE). (For the case of two herbicide tolerance traits the coefficient was positive, however). The negative coefficients are consistent with the findings of Shi, Chavas and Stiegert (2010). However, unlike Shi, Chavas and Stiegert, we obtain positive and significant coefficients for triple stacking, which would indicate super-additive bundle pricing. If our preliminary estimates are confirmed, the apparent inconsistence between sub-additive pricing for double staking and super-additive pricing for triple staking could be an indication that as more traits are stacked, there can be a point at which the marginal economies of scope no longer exceed the marginal

costs of bundling. However, it is also possible that the inconsistence found in these preliminary estimates is due to the lack of control for market concentration in the hedonic function as well as for possible weaknesses of our instruments in the two-stage least squares method.

Regarding the other significant variables, the price of seed was associated with location (table 3). Relative to latitude, moving from north to south, seed price increased linearly. The change in seed price with longitude, moving from east to west, was negative but not significant. At the state level and taking Illinois as the base, the following states had significantly lower seed prices: Michigan, Missouri, Ohio, New York, Pennsylvania, and Wisconsin. Corn acreage was not significant.

Concluding Comments

Despite the rapid increase in the adoption of corn, soybean, and cotton GE varieties by U.S. farmers, questions persist regarding their economic and environmental impacts, the evolution of weed resistance, and consumer acceptance. Thus, genetically engineered crops have been a subject of discussion for many years now. In particular, regarding seed prices, Fernandez-Cornejo et al. (2014) report the rapid increase in adoption of stacked trait seeds and note that various studies of stacked GE seed varieties have found that stacked seeds are priced less than the sum of their component values (Stiegert et al., 2010). According to Shi et al. (2008, 2010), sub-additive pricing is consistent with "the presence of economies of scope in seed production." Moreover, these scope economies are consistent with "synergies in R&D investment (treated as a fixed cost)" across stacked-trait seeds that can contribute to reducing total cost (Shi et al., 2010).

Shi et al. (2009) found that while increased concentration in the seed industry has contributed to higher seed prices, complementarity effects in production and distribution mitigate

these effects. Kalaitzandonakes et al. (2010-11) conclude that, while estimation of market power and associated price markups is not straightforward, the U.S. seed industry shows both "moderate market power" and dynamic market efficiency (as indicated by the balance between firm profits and investments in product quality and innovation) over their period of analysis (1997-2008).

This paper presents preliminary empirical results of the relative influence of quality characteristic and other factors (such as location) on seed pricing. Our preliminary econometric results are mixed. Based on corn data for 2010, we find that in the majority of the cases double-stacking of seed traits implies sub-additive pricing while the two cases of triple-stacking of seed trait imply super-additive pricing.

The next step in this research will be to examine the influence of market concentration on seed prices and to improve the econometric estimation, particularly in finding better instruments to correct for endogeneity bias. In future work we will also consider improvements in the model specification after developing a good measure of germplasm quality. In addition, we will provide enhancements to survey questionnaires to accommodate new seed varieties and their quality characteristics.

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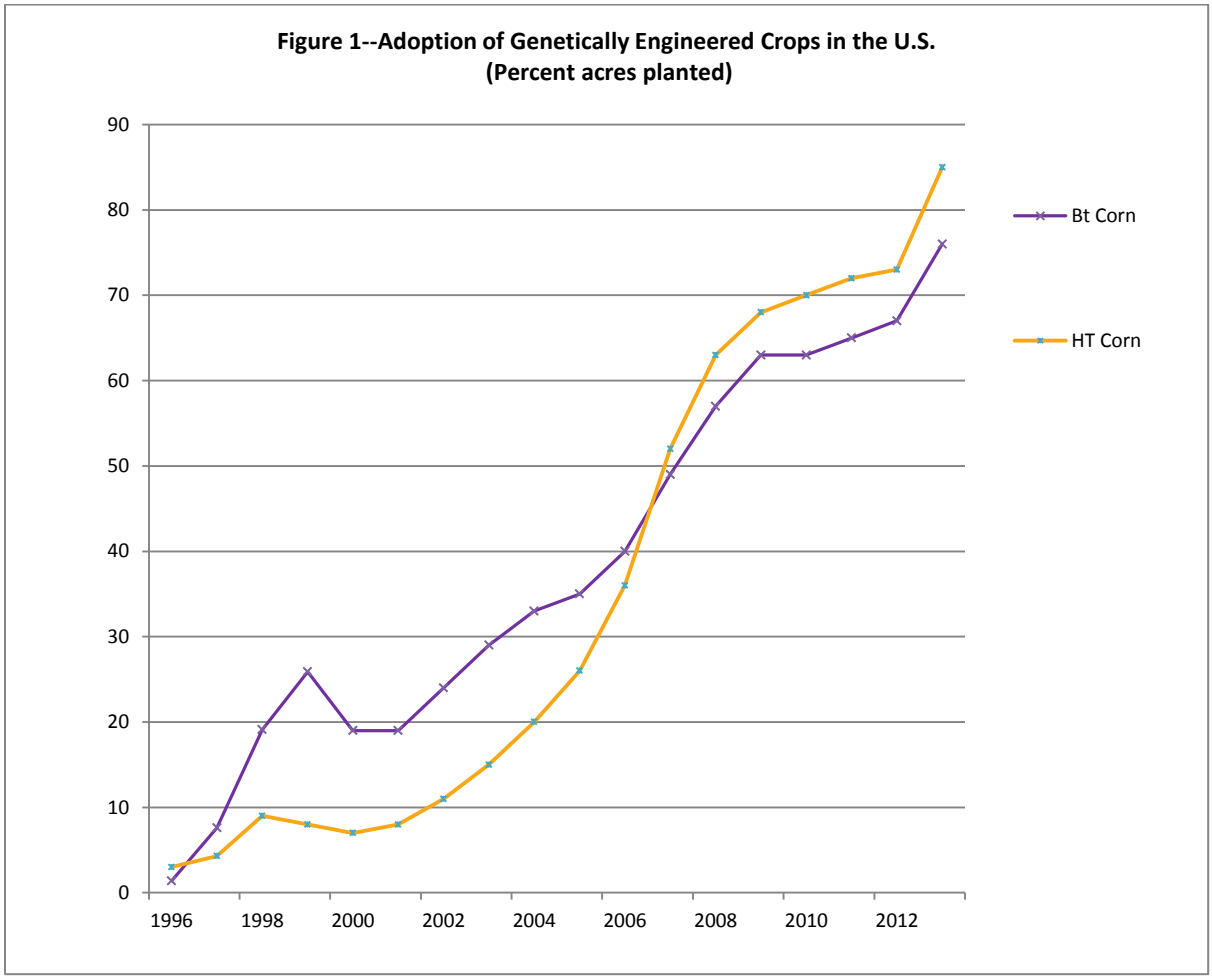
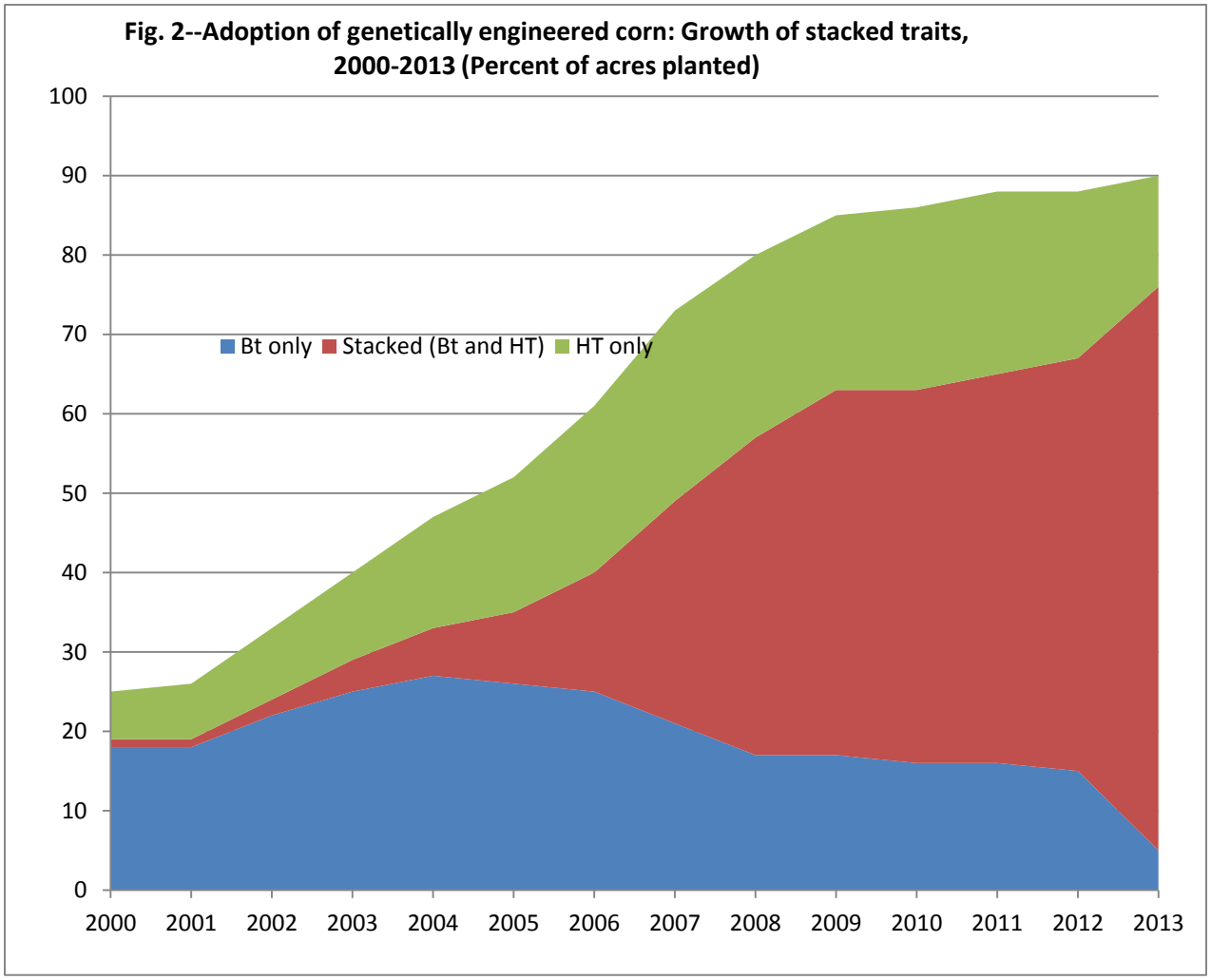


Source: Data from Fernandez-Cornejo (2013)



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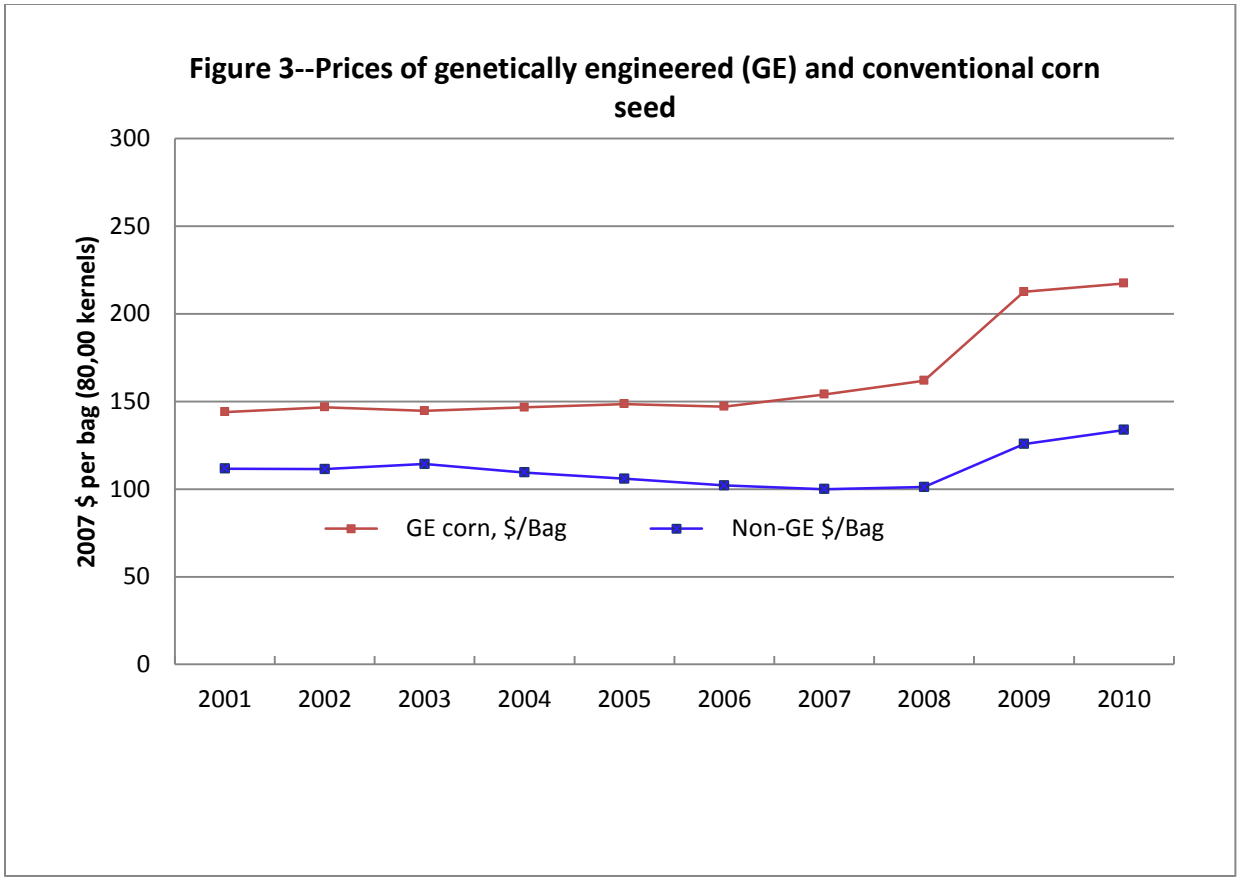

Source: Fernandez-Cornejo et al. (2014) using data from USDA/NASS Agricultural Prices, various years.

Table 1--Weighted Means of Variables of Interest, Corn 2010

Variable	Mean	Label
Seed_Price	204.81	Seed price, $ per bag [1/]
Seeding_rate	20.37	Seeding rate, pounds per acre
Yield_for_grain	148.91	Yield for grain, bushels per acre
Corn_acreage	0.26	Corn acreage measured in thousands of acres
Long_dev	17.09	Longitude deviations from longitude minimum
Long_dev_squared	330.24	Long_dev raised to the second power
Latit_dev	15.18	Latitude deviations from latitude minimum
Lat_dev_squared	239.45	Latit_dev raised to the second power
CONVENTIONAL	0.09	Conventional seed, non-GE
BTECB	0.06	Bt variety for insect resistance to control the European corn borer
BTCRW	0.03	Bt variety for insect resistance to control the corn rootworm
HTGE	0.21	GE herbicide tolerant seed variety
HTNonGE	0.04	Non-GE herbicide tolerant seed variety
BTECB_BTCRW	0.04	Stacked gene variety with both GE traits: Bt-ECB and Bt-CRW
D(HTGE_HTGE1	0.05	Stacked gene variety with two GE herbicide tolerant traits
BTECB_HTGE	0.08	Stacked gene variety with a Bt-ECB trait and a herbicide tolerant trait
BTCRW_HTGE	0.07	Stacked gene variety with a Bt-CRW trait and a herbicide tolerant trait
BTECB_BTCRW_BTCEA [2/]	0.06	Stacked gene variety with BtECB, BtCRW and BtCEA (that controls corn earworm)
BTECB_BTCRW_HTGE	0.27	Stacked gene variety with a Bt-ECB, Bt-CRW plus a herbicide tolerant trait
QUADRUPLE STACK OR MORE	0.01	Multiple trait stacked variety with several Bt traits and 2 herbicide tolerant traits

[1/] 80,000 kernels per bag. There are approximately 1450 kernels per pound.

[2/] Seed types with no reported use are not included. For example, the corn seed variety with a Bt trait to control the corn earworm was only sold in a triple-stacking version and is only shown as such in this table.

Source: ARMS data for 2010 corn.

Table 2- Seed Price and Seeding Rates by GE Seed Trait, Corn, 2010

Seed type	Seed Price, $ per bag[1/]	Seeding rate, pounds per acre
CONVENTIONAL	148.79	19.39
BTECB	205.81	20.50
BTCRW	216.25	20.23
HTGE	183.28	18.98
HTNonGE	159.71	20.09
BTECB_BTCRW	205.06	20.81
HTGE_HTGE1	210.78	19.38
BTECB_HTGE	206.68	20.77
BTCRW_HTGE	221.02	20.99
BTECB_BTCRW_HTGE	232.00	21.34
BTECB_BTCRW_BTCEA	242.64	21.67
QUADRUPLE STACKING OR MORE	247.69	21.57
ALL	204.81	20.37

[1/] 80,000 kernels per bag.

Source: ARMS data for 2010 corn.

Table 3-Regression Results – Hedonic Function Two-Stage Least Squares Estimation

Variable	Parameter Estimate	Standard error	t Value	Pr > |t|
Dependent variable: Log P				
BTECB	0.314	0.033	9.62	<.0001
BTCRW	0.375	0.043	8.7	<.0001
HTGE	0.218	0.024	8.9	<.0001
HTNonGE	0.071	0.036	1.99	0.0463
BTECB_BTCRW	-0.386	0.059	-6.59	<.0001
HTGE_HTGE1	0.140	0.032	4.36	<.0001
BTECB_HTGE	-0.206	0.041	-5.02	<.0001
BTCRW_HTGE	-0.192	0.051	-3.8	0.0002
BTECB_BTCRW_HTGE	0.321	0.069	4.69	<.0001
BTECB_BTCRW_BTCEA	0.178	0.040	4.44	<.0001
QUADRUPLE STACK OR MORE	-0.050	0.078	-0.64	0.5193
Constant	4.779	0.265	18.04	<.0001
Seeding_rate_Hat	0.001	0.008	0.17	0.8616
long_dev	-0.015	0.014	-1.11	0.2687
latit_dev	0.046	0.025	1.79	0.0735
long_dev_squared	0.000	0.000	0.35	0.7298
lat_dev_squared	-0.001	0.001	-1.18	0.2371
Colorado	0.116	0.139	0.83	0.4046
Georgia	0.170	0.104	1.64	0.1011
Indiana	0.010	0.035	0.28	0.778
Iowa	-0.006	0.035	-0.17	0.864
Kansas	0.098	0.067	1.46	0.1449
Kentucky	-0.101	0.062	-1.64	0.1014
Michigan	-0.176	0.053	-3.31	0.001
Minnesota	-0.025	0.047	-0.53	0.5966
Missouri	-0.086	0.039	-2.21	0.0276
Nebraska	0.050	0.053	0.94	0.3467
new_york	-0.365	0.115	-3.17	0.0015
north_carolina	-0.036	0.106	-0.34	0.7319
north_dakota	-0.020	0.086	-0.24	0.8141
Ohio	-0.223	0.048	-4.64	<.0001
Pennsylvania	-0.228	0.095	-2.41	0.016
south_dakota	0.057	0.055	1.03	0.3022
Texas	0.257	0.117	2.2	0.0282
Wisconsin	-0.216	0.040	-5.36	<.0001
corn_acreage	0.002	0.019	0.12	0.9008
Root MSE	3.14451	R-Square		0.3783
Dependent Mean	5.28498	Adjusted R-Square		0.3622

Source: Model estimates based on 2010 corn data from ARMS.

Table 4--Seed Price Premium over the Price of Conventional Seed, Corn, 2010

Seed Type	Seed price relative to conventional seed	Price premium over conventional seed, $ per bag
BTECB	1.368	54.81
BTCRW	1.455	67.70
HTGE	1.243	36.20
HTNonGE	1.074	10.99
BTECB_BTCRW	0.679	-47.69
HTGE_HTGE1	1.150	22.33
BTECB_HTGE	0.814	-27.71
BTCRW_HTGE	0.825	-26.03
BTECB_BTCRW_HTGE	1.378	56.32
BTECB_BTCRW_BTCEA	1.194	28.91
QUADRUPLE STACKING OR MORE	0.951	-7.32

All the underlying coefficients are significant except the last one (See table 3)

Source: Model estimates based on 2010 corn data from ARMS.