Look Inside A Seed
An Analysis of the Demand for Traits in the U.S. Corn Seed Market

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Selected Paper prepared for presentation at the 2019 Agricultural & Applied Economics Association Annual Meeting, Atlanta, Georgia, July 21-July 23

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(working paper)

1. Introduction

The application of genetic engineering (GE) to agriculture commercially introduced plant-incorporated-protectants (PIPs) and herbicide tolerant traits to corn and other crops. PIP traits make it so the corn plant produces proteins that are toxic when consumed by the European corn borer (ECB) and corn rootworm (CRW). While with herbicide tolerant traits (HT), such as Roundup Ready and Liberty Link, corn plants manage to survive exposure to herbicide that would normally kill it. The ultimate goal of this study is to assess the economic-biological impacts of the introduction and diffusion of GE varieties in the U.S. corn market. To achieve this, we investigate the farmers' willingness to pay for GE traits.

Since its first commercial introduction in 1996, GE corn varieties have contributed to agricultural productivity growth and exhibited rapid adoption among U.S. farmers (Fernandez-Cornejo 2004). From 2000 to 2010, GE corn planted area for all purposes expanded from 20 percent to 90 percent of the total U.S. corn acreage. There are two crucial factors of GE corn variety demand: the price of GE corn seed and the efficacy of the GE trait. GE corn seed is the product of direct manipulation of the genetic makeup, and may be patented by different biotech firms. A GE seed can carry either a single trait or a combination of several traits. If a seed includes more than one trait, it is referred to as stacked if the different traits target different pests; or pyramided if the different traits are target the same pest; or both. When marketed to farmers, GE seeds are typically priced higher than conventional seeds (seeds that are not genetically engineered), while stacked or/and pyramided seeds are priced higher than single-trait seeds (Shi, Chavas, and Stiegert, 2010). From a business operating perspective, seed trait bundling has become a well-known business strategy for firms with patent rights to increase market share, prices and profit. Note that the marginal production cost of GE varieties is approximately the same as the marginal production cost of conventional varieties (Ciliberto, Moschini and Perry, 2017). The marginal cost of inserting one more gene into corn seed is much lower compared to the profit increase brought by patent rights. Moreover, the U.S. corn seed markets have changed significantly over last twenty years (Fernandez-Cornejo 2004). Through ongoing restructuring and consolidation, by 2007, patented seeds from six biotech firms were planted on over 75 percent of U.S. corn acreage (Stiegert, et al., 2010). Therefore, the bundling, bundle pricing and strategic behavior of seed firms under imperfect competition will all be reflected in the price of GE corn seed.

There exists limited research on the pricing of traits in the U.S. corn seed market. Shi, Chavas and Stiegert (2010) estimate hedonic regressions and find that, GE seeds generated statistically significant premiums over conventional seeds, which can be driven by price discrimination associated with imperfect competition. Their empirical results also indicate the potential prevalence of sub-additive pricing of stacked GE traits. Such trait bundle pricing offers benefits to farmers exhibiting strong demand for multiple complementary traits (Shi, Chavas, Stiegert and Meng, 2012). By examining a discrete choice model, Ciliberto, Moschini and Perry (2017) examine the welfare impact of GE traits. From their demand estimates, they find that not only are farmers willing to pay a significant premium for GE traits stacked in seed, but the extent of this willingness to pay has increased significantly over time.

Besides analyzing the bundle pricing and premium in price, Ma and Shi (2013) find that the embedded stacked GE traits, contribute significantly to the survival of corn seed varieties, which leads to our discussion of the other factor of GE corn demand. High efficacy and full season control provided by the GE traits result in the rapid adoption by farmers, while the rapid adoption raises concerns that the pests and weeds will develop resistance (Secchi, Hurley, Babcock and Hellmich, 2006). Resistance management (RM), aiming to prevent or slow the evolution of resistance, is an application of population genetics and ecology (Onstad and Gassmann, 2014).

For a specific type of pest, assume resistance is a monogenic trait that resides at a single locus with one allele for resistance and a second allele that confers susceptibility. With no cross resistance, pyramiding GE traits into one corn plant is a simple strategy to delay the resistance. From an RM perspective, the GE trait pyramiding can be beneficial because there is a smaller chance for a pest to survive and develop multiple monogenic resistances simultaneously when exposed to multiple GE traits. However, having multiple stacked traits built into the plant may also be detrimental because it is impossible to limit exposure to GE traits when the severity of a pest infestation is not bad enough to justify the expense of management, thereby making pests less controllable in the future with little if any contemporary benefit in return.

Additionally, discovering and commercially developing a new GE trait is both time-consuming and costly. Once the trait is incorporated into a plant, natural breeding can be used to propagate the trait. And it is uncertain how fast pesticide resistance will emerge or even if it will emerge before the next new corn seed traits are discovered (Hurley and

Frisvold, 2016). Thus, the timing of commercial introduction of pyramided-trait GE corn seed is crucial to address the evolution of resistance in pests.

Apart from studies testing the sensitivity of farmers' demand for GE corn seeds, little is known about how the efficacy of the GE trait is reflected in the price and valued by farmers. Taking a step towards filling this gap, the purpose of this chapter is to explore how farmers value pyramided seed products as well as stacked seed products. This analysis is related to, but distinct from previous work that assesses the value farmers place on general GE traits. This analysis focuses more on how the GE traits are combined into seeds, both by stacking and pyramiding. To achieve this, the seed products are grouped in two dimensions: by the number of pests the embedded traits target for control (Shi, Chavas and Stiegert, 2010; Shi, Chavas, Stiegert and Meng, 2012; Ciliberto, Moschini and Perry, 2017), and by the total number of traits in the seed. Additionally, by using more recent data (2000-2014), we are able to capture more details of farmers' multi-trait seed purchases, compared to work done by Shi, Chavas and Stiegert (2010), using data to 2007; or by Ciliberto, Moschini and Perry (2017) using data to 2011.

The paper is organized as follows. In section 2, we provide an overview of the U.S. corn seed market, followed by a description of data used in the econometric analysis. Section 3 presents an explicit discrete-choice farmers' seed demand model. The estimation method and econometric results are then presented. Finally, we discuss the empirical findings and their implications.

2. The U.S. Corn Seed Market

We use proprietary U.S. corn seed market data (collected by GfK Kynetee)[1] for the empirical analyses. The data were collected by GfK Kynetec (GfK) using computer assisted telephone annual interviews during the month of June. A stratified sample of U.S. corn farmers is surveyed, but not all farms surveyed remain in the sample. Thus, the data is not a balanced panel. The surveys provide farm-level information on corn seed purchases, corn acreage, seed types, seed quantity and seed prices.

Figure **错误!文档中没有指定样式的文字。** displays four maps computed from the GfK data. The maps show the allocations of counties surveyed in 2000, 2007, 2010 and 2014. The data do not have balanced panel structure, but most of the Midwest corn planting area is covered. To create these maps, we sum up the number of traits embedded in each seed, ignoring which pest those traits target, and calculate the market share for each seed-type group. The maps are filled with the color of the largest seed-type group in each county. We can observe that the Midwest states, such as Minnesota, Iowa, Wisconsin and Illinois, are not only the major corn planting states, but also quick in adopting new seed varieties and with larger scale. Meanwhile, as mentioned by Shi, Chavas and Stiegert (2010), the maps also show the spatial heterogeneity in the U.S. corn seed market. For example, in 2014, despite the rapid adoption of sextuple-trait seed in Minnesota, conventional and single-trait seed still dominate in some crop reporting districts (CRDs) in Wyoming.

Together with Table 1, and the plots in Figure 3, the evolution of seed products can be captured. Before 2000, GE seeds were not adopted by most of the farms. By 2000, around

[1] Web address: www.gfk.com. The seed data set is one of their products, called TraitTrak.

30% of corn acres are planted with single-trait seed. The demand for double-trait ECB- and HT-trait seed has been large since around 2005, and shortly after that, triple-trait ECB-, CRW-, and HT-trait seed has held the market since. Over the past decades, the market share for conventional seed dropped from 98.2% in 1995 to 6.2% in 2014.

On the other hand, the market has been becoming more diverse. Figure4 shows changes in seed product diversity in the market since 2000. The four maps display the values of the Herfindahl-Hirschman index (HHI), calculated by squaring the market share of each seed type[2] competing in a market, and then summing the resulting numbers, which produces an index ranging from zero to one. The market would be dominated by one seed product with a HHI equal to 1; and the variety of products increases as the value of HHI approaches zero. The value 0.18 is taken as a threshold; an HHI with value below 0.18 would indicate a moderately concentrated market (Diallo and Tomek, 2015). Again, though the HHI density is moving toward zero gradually, there are still some local CRDs with a high concentration in seed products.

Figure 5 displays the changes in market structure since 2000. Except for some CRDs, monopolistic market structure is not prevalent across the U.S. Corn Belt. The average low values of HHI of seed types may not look as optimistic if we take a look at Figure 6. Fernandez-Cornejo (2004) stated that the corn seed industry was dominated by six[3] large biotech firms. While the data used in this analysis specify five big parent company names, and cluster all the other seed companies into “other”, Figure 6 indicates that, around 70% of seeds purchased in recent years are from Monsanto and Dupont. Even though the other

[2] Again, the seed types used in the map are groups of seed products with same number of traits.
[3] Six biotech firms: Monsanto, Syngenta, Dow Agrosciences, DuPont, Bayer CropScience, and BASF.

three companies experience some market share loses (see Table 2), the sum of the big 5 companies' market share has been maintained around 85% of the total market share for the last two decades.

The prices of seed products have been growing over the years. As displayed in Table 3 and Figure 7, the average prices of nearly all seed products have doubled compared to that of the first year the product was introduced to the market. Across the seed products, the price of ECB-CRW-HT stacked seed is about 30 dollars more than the price of conventional seed in recent years.

a. The Model

Suppose a farmer's utility is the utility from the consumption of all products (including conventional product) available in the market, together with consumption of an outside good. Let q_n denote the quantity purchased of a product n, where $n = 0$ represents the outside good. The farmer chooses product such that:

$$\max_{q_0, q_1, \ldots, q_{50}} u_0(q_0) + u_1(q_1) + u_2(q_2) + \cdots + u_n(q_n) \qquad 1$$

$$\text{s.t.,} \qquad \textstyle\sum_{j=0}^{n} \{q_j p_j\} \leq y$$

$$\textstyle\sum_{j=0}^{n} \{q_j\} \leq 1.$$

The first constraint is the budget constraint, and the second constraint requires that the farmer can buy no more than one of the n products, or the outside good ($q_0 = 1$). This gives us the standard multinomial logit model. If the farmer were to buy corn seed product j in market t, the utility function reduces to the following form (Nevo, 2000):

$$u_{ijt} = \alpha_i (y_i - p_{jt}) + \mathbf{x}_{jt} \boldsymbol{\beta}_i + \xi_{jt} + \varepsilon_{ijt}, \qquad 2$$

where y_i is the income of farmer i. Since the farm income is unobserved for this study, we assume it does not vary across time. The observed price of seed product j in market t is p_{jt}. Vector $\mathbf{x}_{jt}$ comprises indicator variables that code for the presence of one or more GE traits, and GE trait bundle methods in seed product j in market t (these variables take value zero for conventional seed products). The variable $\xi_{jt}$is a disturbance scalar for unobserved characteristics of product j in market t, and ε_{ijt} is the usual unobserved disturbance with mean zero. Parameters to be estimated are α_i and $\boldsymbol{\beta_i}$ where α_i is farmer i's marginal utility of income and $\boldsymbol{\beta_i}$ is the marginal utilities of the alternative product characteristics. If farmer i chooses not to buy any product (neither conventional seed nor GE seed products), there will be an outside option that is normalized with zero price and zero characteristics values: u_{i0t}=$\alpha_i y_i + \varepsilon_{i0t}$. If all farmers in the market are identical, the aggregate utility can be written as:

$$u_{jt} = \alpha(y - p_{jt}) + \mathbf{x}_{\boldsymbol{jt}}\boldsymbol{\beta} + \xi_{jt} + \varepsilon_{jt}.$$

Assuming that ε_{ijt} follows the Type I extreme-value distribution,[4] the market share of product j can be derived as:

[4] If the Type I extreme-value distribution has mean zero and a scale parameter of 1, it has the density and cumulative distribution $f(x) = e^x e^{e^{-x}}$ and $F(x) = e^{-e^{-x}}$. Thus, the more draws, the bigger the expected maximum.

$$s_{1t} = \Pr(u_{ij} \geq u_{ik}, \forall k) \quad 3$$

$$= Prob(\alpha(y - p_{1t}) + \mathbf{x_{1t}\beta} + \xi_{1t} + \varepsilon_{1t} > \alpha(y - p_{2t}) + \mathbf{x_{2t}\beta} + \xi_{2t} + \varepsilon_{2t})$$

$$* Prob(\alpha(y - p_{1t}) + \mathbf{x_{1t}\beta} + \xi_{1t} + \varepsilon_{1t} > \alpha(y - p_{3t}) + \mathbf{x_{3t}\beta} + \xi_{3t} + \varepsilon_{3t})$$

$$* \ldots$$

$$* Prob(\alpha(y - p_{1t}) + \mathbf{x_{1t}\beta} + \xi_{1t} + \varepsilon_{1t} > \alpha(y - p_{nt}) + \mathbf{x_{nt}\beta} + \xi_{nt} + \varepsilon_{nt})$$

$$* Prob(\alpha(y - p_{1t}) + \mathbf{x_{1t}\beta} + \xi_{1t} + \varepsilon_{1t} > \alpha y + \varepsilon_{0t})$$

$$= \frac{e^{\mathbf{x_{jt}\beta} - \alpha p_{jt} + \xi_{jt}}}{e^0 + \sum_{k=1}^{n} e^{\mathbf{x_{kt}\beta} - \alpha p_{kt} + \xi_{kt}}},$$

in which, $e^0 = 1$ is from the outside good, because it adds 0 to utility. Therefore, the market share of outside product is $s_{1t} = \frac{1}{1 + \sum_{k=1}^{n} e^{\mathbf{x_{kt}\beta} - \alpha p_{kt} + \xi_{kt}}}$. Rearranging the market share equation, a linear estimating equation is obtained:

$$\ln(s_{jt}) - \ln(s_{0t}) = \mathbf{x_{jt}\beta} - \alpha p_{jt} + \xi_{jt}. \quad 4$$

The corresponding price elasticities are: $\eta_{kt} = \begin{cases} -\alpha p_{kt}(1 - s_{jt}), & j = k \\ \alpha p_{kt} s_{kt}, & j \neq k \end{cases}$, such that the own-price elasticity is inversely proportional to its own price, and cross-price elasticity depends on price and market share of product k. The cross-price elasticity is unrealistic, because it implies that if product k raises its price, it loses farmers equally to each other product. Despite the problematic implication for elasticities, we choose to use this Logit model to estimate for following reasons.

First, from the data we are using for this analysis, there are over 1,500 companies selling corn seed in the U.S. corn seed market. Their products may include conventional and/or GE seeds, where GE seeds can be single-trait or multiple-traits. If seeds have multiple traits, it can be stacked seed, pyramided seed or stacked/pyramided seed. To date, for either pests (such as ECB and CRW used in the analysis), or HT, there are 2 to 4 different traits[5] commercialized in the U.S. corn seed market. Therefore, the main difference among all seed products is how the company combines the traits, and which traits they use. It will be ideal if we can assume farmers behave randomly, and utility is associated with both fixed coefficients and observed/unobservable farm-level characteristics, which is the so-called "BLP Method" of econometric estimation, named after Berry, Levinsohn and Pakes (1995). However, we were unable to conduct BLP method due to a lack of fine data on observable farm characteristics.

Second, considering all the PIP traits targeting ECB and CRW, and HT traits commercialized and available in the U.S. corn seed market, there are 33 types of trait combinations observed in the data. Figure 2 shows the changes of market shares for all seed products. The product labeled C1 represents the conventional corn seed; it occupied the market until GE seed was introduced in 1995. Over time, there were single- and double-trait seeds sold in the market, and lately quintuple- and sextuple-trait seeds (labeled C28-C33 in Figure 2) started to show up and gain market share. A number of seed products disappeared not long after market introduction. Given the large amount of short life-cycle seed products, it is difficult to apply the Almost Ideal Demand System (AIDS) specification of Deaton and Muellbauer (1980). The AIDS model emphasizes the product space, rather than characteristic space. When applying the AIDS model, estimating the demand of a new product, or a short life-cycle product requires estimates of all the parameters associated

[5] Three traits targeting ECB: Cry1Ab; Cry1A.105+Cry2AB2; Cry1F.
Four traits targeting CRW: eCry3.1Ab; Cry3Bb1; Cry34Ab1/Cry35Ab1; mCry3A.
Two HT targeting weeds generally: PAT(LL); EPSPS(RR/GT).

with that product. This limits the applicability of the model in the seed market case, because there is not enough data to estimate those parameters.

Ciliberto, Moschini and Perry (2017) develop a discrete-choice model of differentiated products for the corn and soybean seed industry in the U.S. by using the same data as this analysis. They model the demand for corn and soybean seed products using a two-level nested logit specification (Verboven 1996; Bjornerstedt and Verboven 2016). In their model setting, they consider two subgroups (one for soybean seed products and the other for corn seed products) as the inside options. Their outside option is planting a crop other than corn or soybeans, or not planting at all. GE soybean seeds are only embedded with at most two HT traits. We do not think the presence of GE soybean seeds and these traits will affect the relative odds between single- and multiple- stack corn seeds, or between pyramid- and non-pyramid corn seeds. Also, this analysis does not consider crop rotation by including soybean seed products. Thus, there are no independent groups that can be used to specify a hierarchical model, such as the nested logit model.

b. Estimation

We use GfK U.S. corn seed market data spanning the period of 2000 to 2014 for empirical analyses. The surveys provide farm-level information on corn seed purchases, corn acreage, seed types, seed quantity and seed prices. During the 2000-2014 timeframe, the data contain 230,644 transactions from 81 USDA CRDs. Each farm could and most farms did purchase different corn seed types each year. Therefore, this analysis considers only transactions, rather than farms.

Given the overview of the U.S. corn seed market, we choose to use data from the 2000-2014 timeframe, during which period we can observe the most variation in seed types, seed prices, and seed product market shares. We use a stage indicator which divides the 15 years into 2000-2004, 2005-2009 and 2010-2014 based on the seed variety evolution process discussed above. Geographically, we use data from the U.S. Corn Belt (Stiegert et al., 2011), shown in Figure 8. The whole colored area describes the U.S. Corn Belt.

Define a market as a CRD-year combination. Then, from the 2000-2014 timeframe on the Corn Belt, there are in total 1,205 markets with sample size of 19,822. Define a product as a seed company-seed trait combination. There are 6 company groups: 5 big companies and "other"; 8 seed trait types (conventional, ECB-single, CRW-single, HT-single, ECB-HT-double, ECB-CRW-double, CRW-HT-double, and ECB-CRW-HT-triple), which results in 48 products. We treat all the products sold by "other" companies as the outside options for farmers.

The independent variables include price, seed trait stacking dummy variables, seed trait pyramiding dummy variable, number of years since introduction, and lagged county-level yearly yield.[6] Table 4 displays the variable summary statistics.

There are three types of price available in the data: price/bag, price/unit, and price/acre. In this study, we use price/acre given that the planting density of corn seed is unknown and can be random from farm to farm.

There are 4 seed trait stacking dummy variables, showing if the seed is conventional, single-stacked, double-stacked or triple-stacked. Seed trait pyramiding dummies may take

[6] County level yearly corn yield data are from USDA survey data.

either 1, pyramided, or 0 otherwise. Seed trait stacking dummies and pyramiding dummies capture the most important corn seed characteristics, as well as how the seed products are differentiated from each other.

We also include two variables to indicate the possible efficacy of the seed varieties: number of years since introduction and lagged yield. The number of years since introduction is suggested to have a length-of-usage, or dependability and trust effect on demand for seed varieties (Houston, Jeong and Fletcher, 1989). On one hand, it shows how satisfied with previous use or how loyal the farmer is to the brand. It also gives us the duration for which pests are exposed to the seed variety, and how likely a pest develops resistance to the seed trait.

Ideally, we can have the average experimental yield for each variety in the market, which would show how efficient the seed variety is at boosting agricultural production. Lacking of the experimental yield data, we assume that the yield obtained from previous year, which may reflect the efficacy of seed products purchased in that year, have an influence on farmers' choice of seed for this coming year.

One econometric issue in the specification in equation (4) is the endogeneity of price. There is no problem assuming that each farm's demand had no effect on the market price. If one farm changes its corn seed purchase plan by not buying one seed product, the decrease in sales of that seed product would be so small to be statistically estimated. However, the unobservable variables included in ε_{ijt} for farm i , can also change farm j's seed purchase (Rasmusen, 2006). If a large number of farms change their seed purchases due to the effect of an unobserved variable, then the market supply and demand equilibrium will move to a new point, resulting in a new market price. Since the data used for estimation are aggregated at the market level, endogenous price can be a major concern for identification.

To solve the problem of price endogeneity, instrumental variables will be needed. In this study, we use BLP instruments which represent functions of the characteristics in competing products (Berry, Levinsohn and Pakes, 1995). Ciliberto, Moschini and Perry (2017) use the sums of numbers of competing GE seed products by market, parent company, and crop as instruments for prices, and evaluate values farmers place on the seed product. While our research objects are the combinations of traits, we use the sums of ECB, CRW, and HT traits inserted in the competing products in the same market. The intuition for this set of instruments is that the trait combination in other competing seed products has no direct impact on farm utility for seed product, but through competition, the instruments will impact the prices of the seed products farmers purchase.

To address the price endogeneity problem, we first test for possible endogeneity of price using Durbin-Wu-Hausman test (Wooldrige, 1995). The test is robust and there is strong evidence supporting the endogeneity assumption. To test if the instruments are weakly correlated with the endogenous variables, we conduct Stock and Yogo tests (Stock and Yogo, 2005) and Shea's Partial-R^2 test (Shea, 1997). The test results show strong evidence against the weak instrument null hypothesis. We check the robustness of regression results using 2SLS, GMM and LIML.

We also run 2SLS regression with different fixed effects as robustness tests. Geographically, shown in Figure 8, Stiegert et al. (2011) divide the U.S. Corn Belt into the core and the fringe. The fringe, the light red region, is best described as a corn producing region that is less productive than the core, the dark red center region, and with more competing crops grown than in the core. Stiegert et al. claim that the observed pricing schemes of GE corn varieties benefit farmers more in the fringe than in the core region of the Corn Belt. Given the fact that some states are partially in the core, while, other states are completely in/out of the core, we group the states into three types, and add the state-core fixed effect to examine if farm adoption changes based on the location in the Corn Belt.

Another geographical fixed effect we to check the robustness of the results is the Farm Resource Regions defined in the USDA Economic Research Service (ERS) report (AIB-760, August 2000). As shown in Figure9, the Corn Belt consists of 5 regions designated at the county level. We also include year fixed effects and 5-year interval fixed effects to control for unobservable heterogeneity.

c. Empirical Results

Equation (4) is estimated using 2SLS with heteroscedastic-robust standard errors. Table 5 reports the results. For purpose of comparison, the ordinary least squares (OLS) estimation results are also reported in column 4. The OLS estimate of the price differs substantially from the 2SLS result, suggesting that prices are indeed endogenous (Ciliberto, Moschini and Perry, 2017; Berry, Levinsohn and Pakes, 1995; Trjtenberg, 1989).

The coefficients of the stacking dummies and pyramiding dummy show statistically significant price premiums. In all cases, the estimates are significantly positive implying that farmers are willing to pay a positive amount for each stacked or/and pyramided trait. The same conclusions have been drawn by Ciliberto, Moschini and Perry (2017), except that they do not look into the pyramiding effects. However, this result is different from the sub-additive pricing of stacked GE trait varieties found by Shi, Chavas, and Stiegert (2010). From the coefficient estimates, farmers' willingness to pay for various combinations of GE corn seed traits can be calculated.

Table 7 contains willingness-to-pay (WTP) estimates for each of the GE-trait combinations in each of the three 5-year periods. Because all prices in the analysis are inflated by inflation rate normalized to equal 1 in 2000, all estimates are in real terms (2000 dollars). All of the estimates appear reasonable and are in line with what might be expected given knowledge of seed prices and the observed adoption patterns by farmers. The WTP for the single-stacked corn seed was $5.72 per acre in the first 5-year-period, dropped to $4.27/acre in the 2005-2010 sub-period, and then rose to $18.37/acre in the 2010-2014 sub-period. Pyramided seeds are valued more by farmers compared to stacked-only seed. A similar pattern occurred for the double/triple stacked traits. The drop of value in the 2005-2010 sub-period may result from the drop of corn price. In the 2010-2014 sub-period, corn price increased rapidly hitting record highs in 2012. The increase in output price likely increased farmer WTP, thus, value of single stacked seed products were tripled from 2005-2010 to 2010-2014; and the value of other stacked seed also increased significantly, or doubled.

The five-year period dummies are expected to capture the adoption trend we discussed above. The coefficients show that, farmers would pay less for the GE corn seed varieties from 2005 to 2010, compared to the amount they would pay in other two timeframes. After combining these coefficient estimates of GE traits, the five-year dummy indicates that, between the year of 2005 and 2010, a farmer would like to pay $6.3 less per acre in order to purchase single-trait, non-pyramided GE seed against conventional seed, $0.3 less per acre if the single-trait seed is pyramided. This explains some of the adoption trend seen in Figure 3 where the market share of single-trait seed peaked before the year of 2005 at around 40% of the market, and then dropped to 20% soon after. A similar trend can be found in Table1 where the market share of ECB single-stacked seed decreased rapidly from 20.7% in 2003 to 2.1% in 2008. There is no significant time effect from 2010 to 2014, the statistically significant price premiums during that period mainly come from farmers' values placed on the GE trait varieties.

In all specifications, the coefficients for the number of years since introduction are significantly positive. This implies that farmers would pay more for seed products that they have previously used, which could signal product loyalty. The coefficient estimates of lagged yield are significantly positive, though the impact was quite small. The results indicate that these two seed product efficacy indicators are valid and significantly positive values are placed on them by farmers.

Table 6 shows the estimation results for four different specifications which differ by the types of fixed effects used to control unobserved heterogeneity. The year fixed effects control for temporal changes, while the state-core, and farm resource region fixed effects control for unobserved, time-invariant regional effects. The company fixed effects control for unobserved seed company related effects. Results from the first three columns remain mostly unchanged, though the values of all estimates are almost doubled when we remove the spatial fixed effects in column 3. This may reflect the fact that the geographical effects control for spatial unobservable differences in seed products that are correlated with prices, such as pest resistance pressure, and weed pressure.

d. Concluding Remarks

Results of the present analysis provide direct evidence that farmers value both ways in which GE corn seed traits have been bundled. The number of traits embedded in seed products grows rapidly in recent years, even if they are targeting the same three pest issues as two decades ago. This may result from the evolution of pest resistance to the GE traits after exposure to the GE seed varieties for about twenty years. In this respect, the efficacy of GE seed traits is expected to be an increasingly important element of farmers' demand for seed products.

This analysis assesses the stacking and pyramiding strategies in seed bundling, and considers the efficacy-related factors, such as whether the seed is pyramiding with traits, number of years since the seed product was introduced to the market, and lagged yield. We observed that, all the factors are significantly important to farmers' seed purchasing choices.

This approach is of practical interest to policy makers and companies in the GE seed industry if we extend the work by integrating this demand model with a biological model of the evolution of pest resistance. It would be very interesting to understand how the business strategy of introducing one more GE seed trait can eventually affect the sustainability and resilience of agricultural productivity, and what the policy value is to regulate the commercialization of the GE seed traits.

Table1 GE Corn Trait Adoption, U.S. (% of planted acres)

Year	Conven-tional	CB	RW	HR	CB-RW	CB-HR	RW-HR	CB-RW-HR
1995	98.22%			1.78%				
1996	96.55%	0.70%		2.74%				
1997	91.61%	4.93%		3.46%				
1998	77.30%	14.25%		5.33%		3.11%		
1999	71.85%	18.72%		7.26%		2.17%		
2000	69.43%	19.37%		9.22%		1.97%		
2001	68.03%	15.43%		11.26%		5.28%		
2002	60.45%	19.25%		13.46%		6.84%		
2003	57.82%	20.73%	0.27%	12.66%		8.52%		
2004	50.40%	18.45%	1.01%	16.07%	0.06%	13.44%	0.56%	
2005	38.95%	16.29%	1.20%	20.01%	0.80%	20.50%	1.24%	1.00%
2006	33.53%	10.54%	1.20%	20.83%	1.84%	24.45%	2.30%	5.32%
2007	20.69%	5.59%	0.41%	20.26%	1.36%	29.59%	2.30%	19.80%
2008	12.88%	2.06%	0.08%	20.78%	0.38%	24.29%	0.84%	38.70%
2009	10.16%	1.29%	0.03%	21.10%	0.43%	20.22%	0.30%	46.47%
2010	10.26%	0.58%	0.01%	21.37%	0.13%	16.30%	0.36%	50.99%
2011	8.07%	0.33%	0.00%	19.97%	0.09%	17.22%	0.55%	53.76%
2012	7.77%	0.30%	0.04%	18.84%	0.04%	20.88%	0.66%	51.47%
2013	7.10%	0.39%	0.00%	13.68%	0.01%	26.16%	0.55%	52.10%
2014	6.17%	0.08%		10.86%	0.04%	27.24%	0.28%	55.32%

Source: Computed from GfK Trait Track data.

Table 2 U.S. Corn Seed Market Concentration

---- Market Shares of the Big 5 Companies, 1995-2014

year	Monsanto	Dupont	Syngenta	Dow Agro-sciences	Agreliant	big5
1995	18.6%	42.0%	15.9%	9.5%	1.9%	87.9%
1996	18.6%	42.2%	14.8%	9.5%	2.2%	87.3%
1997	20.0%	38.2%	16.4%	9.9%	2.2%	86.8%
1998	20.7%	35.9%	18.0%	9.5%	2.8%	86.9%
1999	20.3%	41.3%	15.1%	8.0%	3.5%	88.2%
2000	18.5%	39.4%	16.1%	8.1%	4.3%	86.3%
2001	19.2%	37.8%	16.1%	8.5%	3.7%	85.4%
2002	20.4%	37.0%	15.3%	7.4%	3.8%	83.8%
2003	20.5%	37.1%	14.6%	6.4%	4.5%	83.1%
2004	22.6%	35.4%	14.4%	6.0%	4.6%	83.0%
2005	26.1%	33.7%	14.3%	5.3%	4.6%	84.0%
2006	27.5%	33.8%	12.3%	4.9%	5.8%	84.3%
2007	30.7%	32.0%	9.8%	4.7%	5.8%	82.9%
2008	33.5%	33.7%	7.4%	5.0%	6.0%	85.6%
2009	34.4%	33.5%	8.1%	4.5%	5.7%	86.3%
2010	33.1%	34.4%	7.3%	4.3%	6.3%	85.4%
2011	34.5%	33.8%	7.2%	4.4%	6.9%	86.7%
2012	34.6%	34.5%	6.5%	4.2%	6.6%	86.4%
2013	34.1%	35.3%	6.0%	4.5%	6.4%	86.3%
2014	34.1%	33.3%	5.8%	5.6%	6.9%	85.6%

Source: Computed from GfK Trait Track data.

Table 3 Inflation Adjusted Corn Seed Prices

(in 1995 dollar/acre)

year	Conven-tional	CB	RW	HR	CB-RW	CB-HR	RW-HR	CB-RW-HR
1995	22.99			25.07				
1996	23.41	30.85		24.43				
1997	24.68	33.56		26.52				
1998	24.72	34.82		27.91		33.55		
1999	24.74	32.84		27.97		32.74		
2000	24.61	31.69		26.87		29.45		
2001	24.47	32.36		27.05		30.55		
2002	24.47	31.87		26.76		31.42		
2003	24.94	31.67	35.69	27.33		32.22		
2004	25.10	32.23	36.50	27.76	37.63	33.19	37.70	
2005	25.00	30.03	32.96	28.24	36.99	32.60	36.69	38.24
2006	25.37	30.56	33.01	29.63	37.59	33.75	37.99	42.14
2007	25.21	29.85	33.55	30.21	35.42	33.27	35.66	38.88
2008	28.68	33.36	32.78	37.45	40.53	39.59	45.31	48.77
2009	34.05	39.20	29.45	45.39	51.08	46.97	50.21	61.26
2010	35.85	42.72	34.04	48.00	54.15	49.74	51.53	63.82
2011	36.22	46.73	52.96	47.70	38.97	50.92	61.94	63.41
2012	40.34	55.24	48.42	52.49	54.14	55.85	69.69	68.03
2013	43.19	63.24	45.54	53.98	61.41	58.93	69.95	71.77
2014	45.36	62.31		53.75	78.27	61.21	64.74	74.30

Source: Computed from GfK Trait Track data.

Table 4 Summary Statistics

Variable	Description
Price	Averaged price of a product in a market, inflation adjusted in 2000 US dollars/acre
Stacking Pattern Dummies	Stacking Patterns include: conventional seed (base group); single-trait seed; double-trait seed, and triple-trait seed
Pyramiding Dummy	1 if traits are pyramiding in the seed; 0 otherwise
NumYear	Number of years since introduction
Yield	Lagged county level annual corn yield from USDA survey data.
5 Year Group Dummies	Year can fall into [2000,2005); [2005,2010); and [2010,2014].

Variable	Obs	Mean	Std. Dev.	Min	Max
Price	19,822	43.7199	16.6412	2.5217	111.6796
Stacking Pattern	19,822	2.3255	0.9771	1	4
Pyramiding	19,822	0.1644	0.5027	0	3
NumYear	19,822	9.5177	4.6375	1	20
Yield	19,822	137.4943	8.2741	19	201
5-Year Group	19,822	2.0027	0.7635	1	3

Table 5 2SLS, GMM, LIML and OLS Regression with Robust Standard Errors

	2SLS	GMM	LIML	OLS
Price	-0.249***	-0.259***	-0.304***	-0.0112***
	(0.0192)	(0.0195)	(0.0272)	(0.00154)
Stacking-single	1.425***	1.514***	1.847***	-0.394***
	(0.158)	(0.161)	(0.219)	(0.0350)
Stacking-double	3.504***	3.668***	4.320***	-0.0104
	(0.297)	(0.303)	(0.416)	(0.0513)
Stacking-triple	7.780***	8.091***	9.215***	1.595***
	(0.524)	(0.533)	(0.734)	(0.0795)
Pyramiding	0.839***	0.866***	0.953***	0.349***
	(0.0716)	(0.0735)	(0.0894)	(0.0310)
Years Since Introduced	0.255***	0.263***	0.288***	0.111***
	(0.0149)	(0.0152)	(0.0200)	(0.00488)
Lagged Yield	0.00768***	0.00830***	0.0112***	-0.00729***
	(0.00260)	(0.00267)	(0.00318)	(0.00137)
[2005,2010) year effect	-0.362***	-0.377***	-0.243***	-0.876***
	(0.0675)	(0.0691)	(0.0836)	(0.0360)
[2010,2014] year effect	3.148***	3.304***	4.136***	-1.111***
	(0.352)	(0.359)	(0.491)	(0.0652)
Constant	2.129***	2.240***	2.809***	-0.802***
	(0.397)	(0.407)	(0.496)	(0.193)
Observations		19822		

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 6 2SLS Regressions with Fixed Effects

	2SLS			
Price	-0.187***	-0.135***	-0.249***	-0.0364***
	(0.0131)	(0.0133)	(0.0192)	(0.00857)
Stacking-single	0.791***	0.442***	1.425***	-0.283***
	(0.0909)	(0.0923)	(0.158)	(0.0877)
Stacking-double	2.012***	1.484***	3.504***	0.0117
	(0.135)	(0.137)	(0.297)	(0.184)
Stacking-triple	5.125***	4.303***	7.780***	1.644***
	(0.213)	(0.215)	(0.524)	(0.344)
Pyramiding	0.508***	0.464***	0.839***	0.484***
	(0.0466)	(0.0403)	(0.0716)	(0.0457)
Years Since	0.116***	0.136***	0.255***	0.0834***
Introduced	(0.0103)	(0.00913)	(0.0149)	(0.0164)
Lagged Yield	0.00471**	0.00405**	0.00768***	-0.00727***
	(0.00201)	(0.00169)	(0.00260)	(0.00149)
Year	yes	yes		
5 Year Intervals			yes	
Company	yes	yes		
State Core Dummies	yes			
Farm Resource Region Dummies		yes		
Constant	3.061***	1.553***	2.129***	-0.213
	(0.371)	(0.391)	(0.397)	(0.196)
Observations	19822			

Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

Table 7 Willingness-to-pay for GE corn seed products (2000$/acre)

	[2000,2005)	[2005,2010)	[2010,2014]
Single stacked	5.72	4.27	18.37
Single stacked + pyramided	9.09	7.64	21.73
Double stacked	14.07	12.62	26.71
Double stacked + pyramided	17.44	15.99	30.08
Triple stacked	31.24	29.79	43.89
Triple stacked + pyramided	34.61	33.16	47.26

WTP estimates are based on the estimated coefficients of column 1 in Table 5.

Figure 1 Structure of the Corn Seed Product

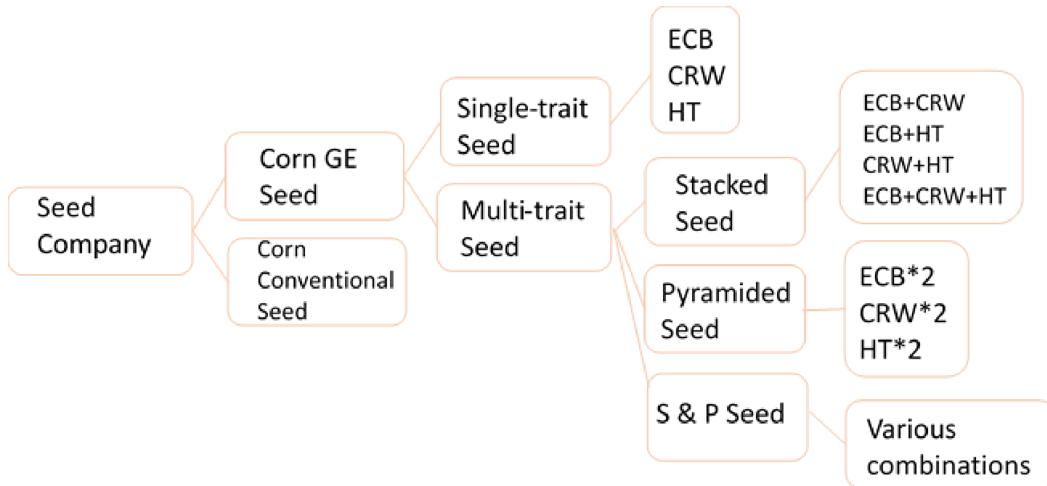
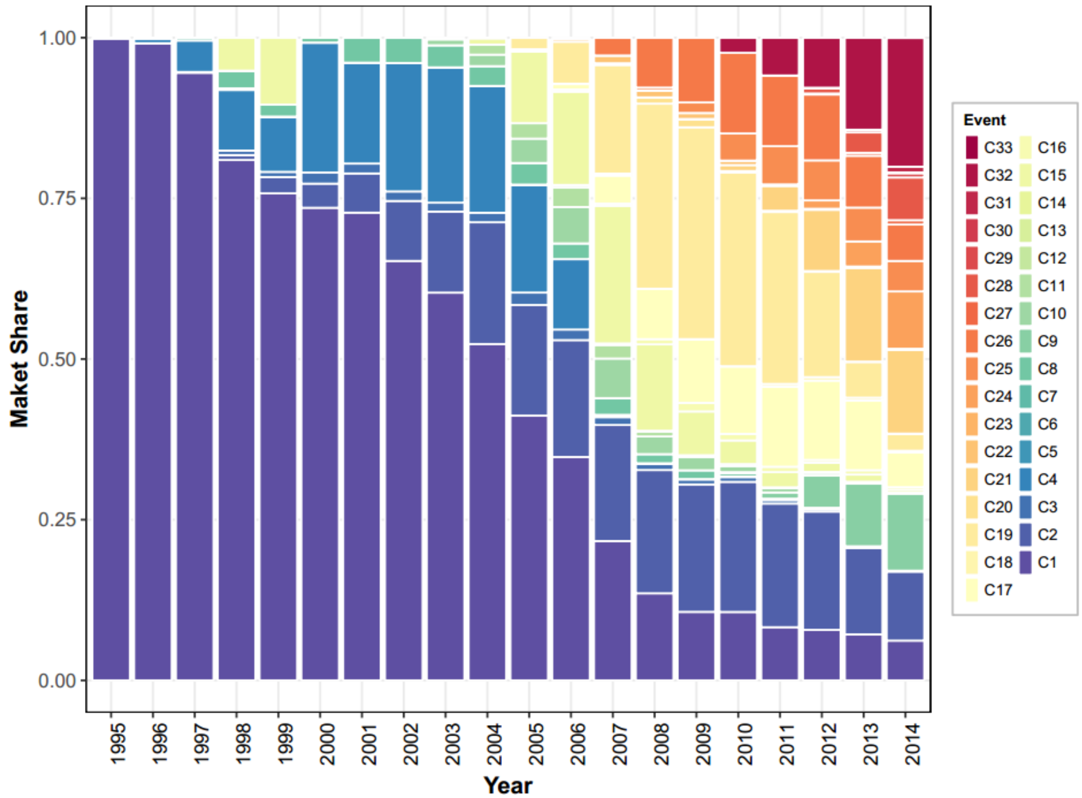


Figure 2 Market Share of Corn Seed Product in the U.S. Corn Seed Market

– Seeds with Different Traits and Traits Combinations



Source: Computed from GfK Trait Track data.

Figure 错误!文档中没有指定样式的文字。 Corn Seed GE Trait Adoption in the U.S. Market

--- Largest Seed-Type Group in Each County; Source: Computed from GfK Trait Track data

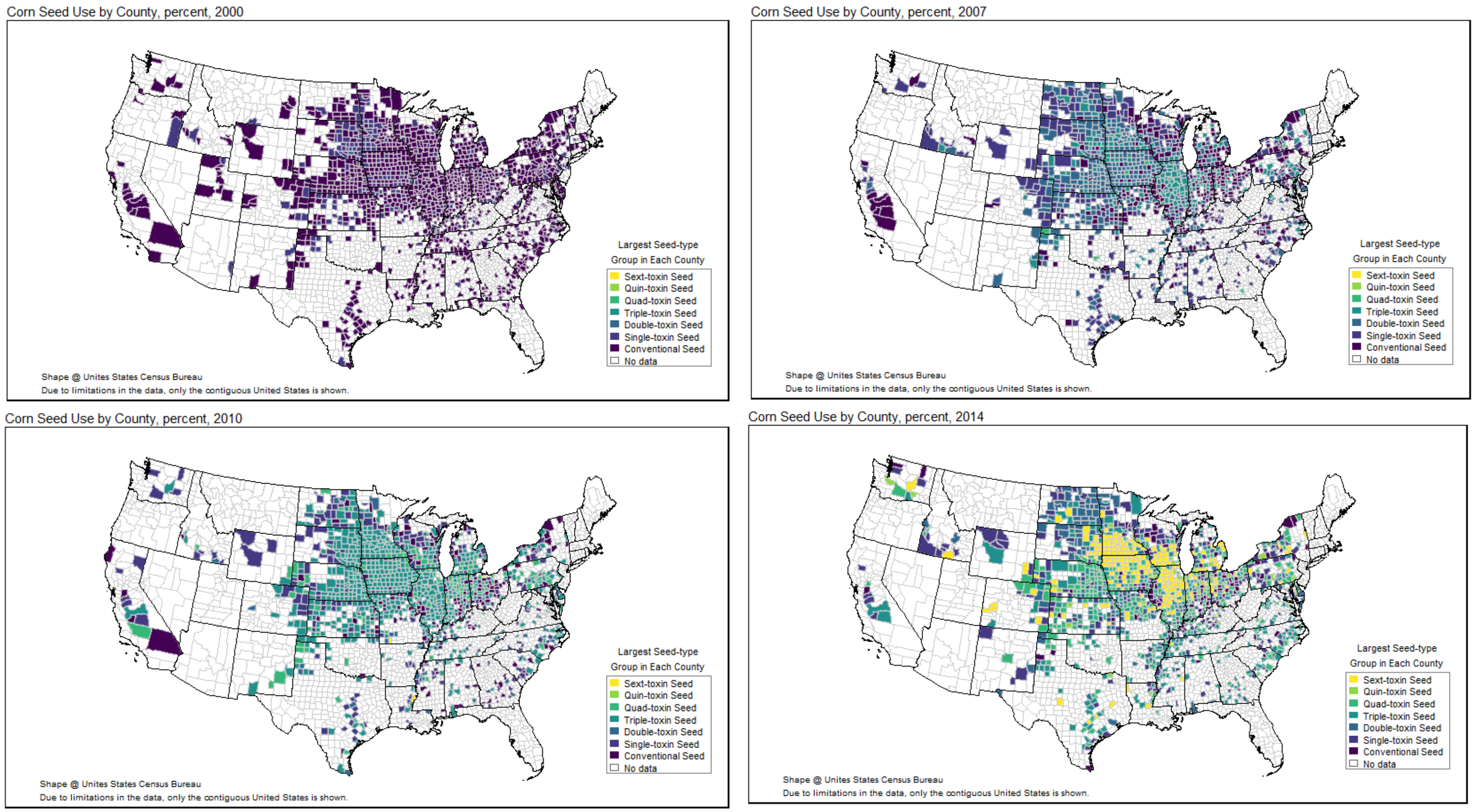
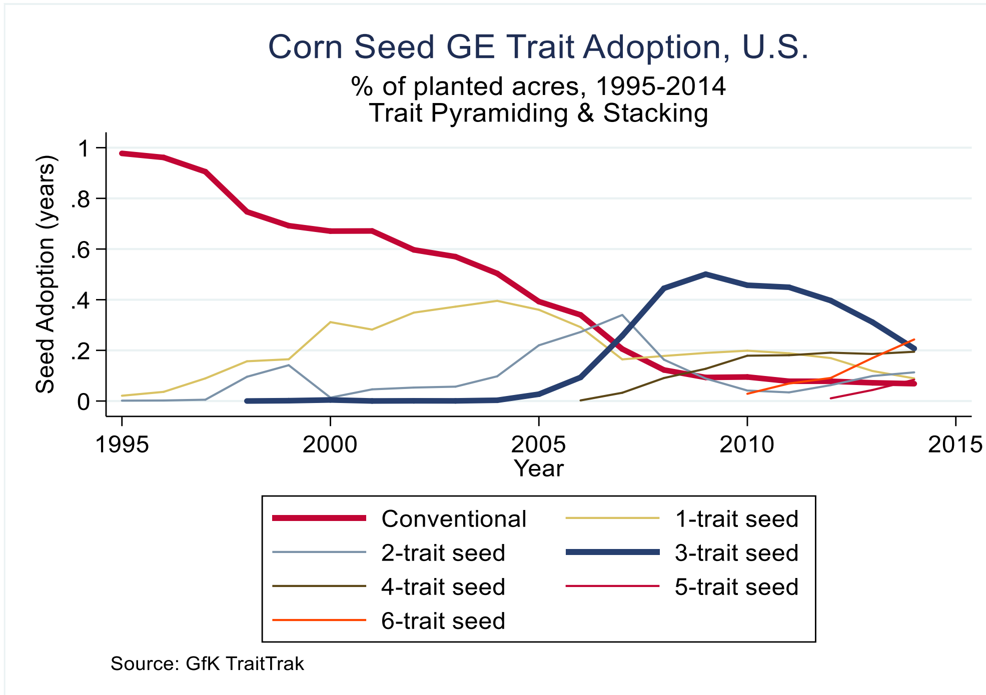


Figure 3 Corn Seed GE Trait Adoption

---- Computed from GfK Trait Track data



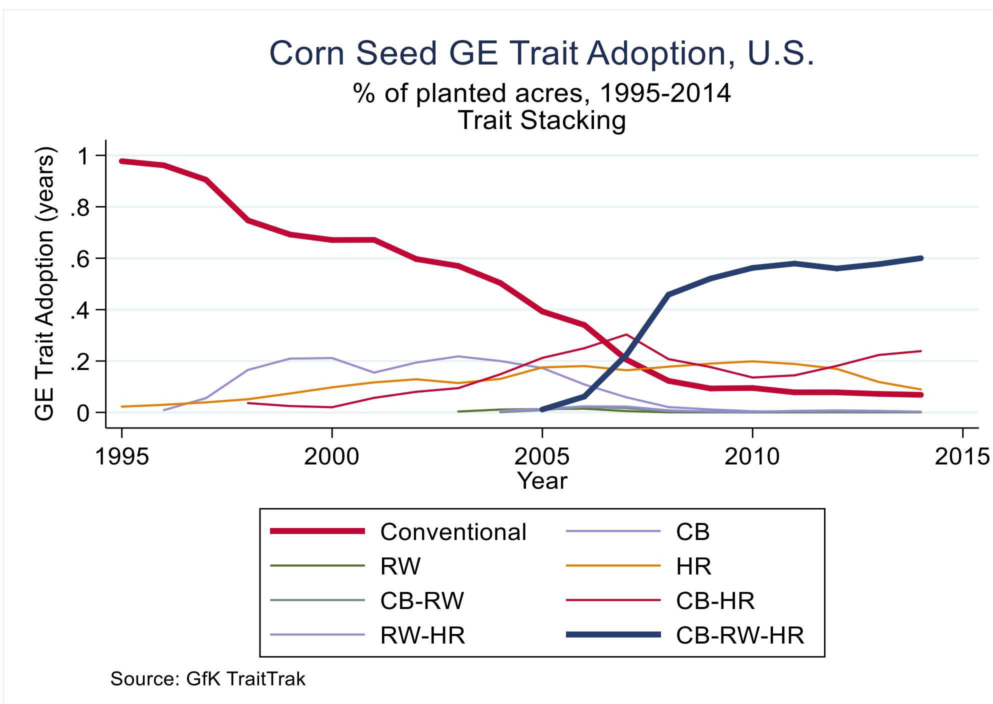
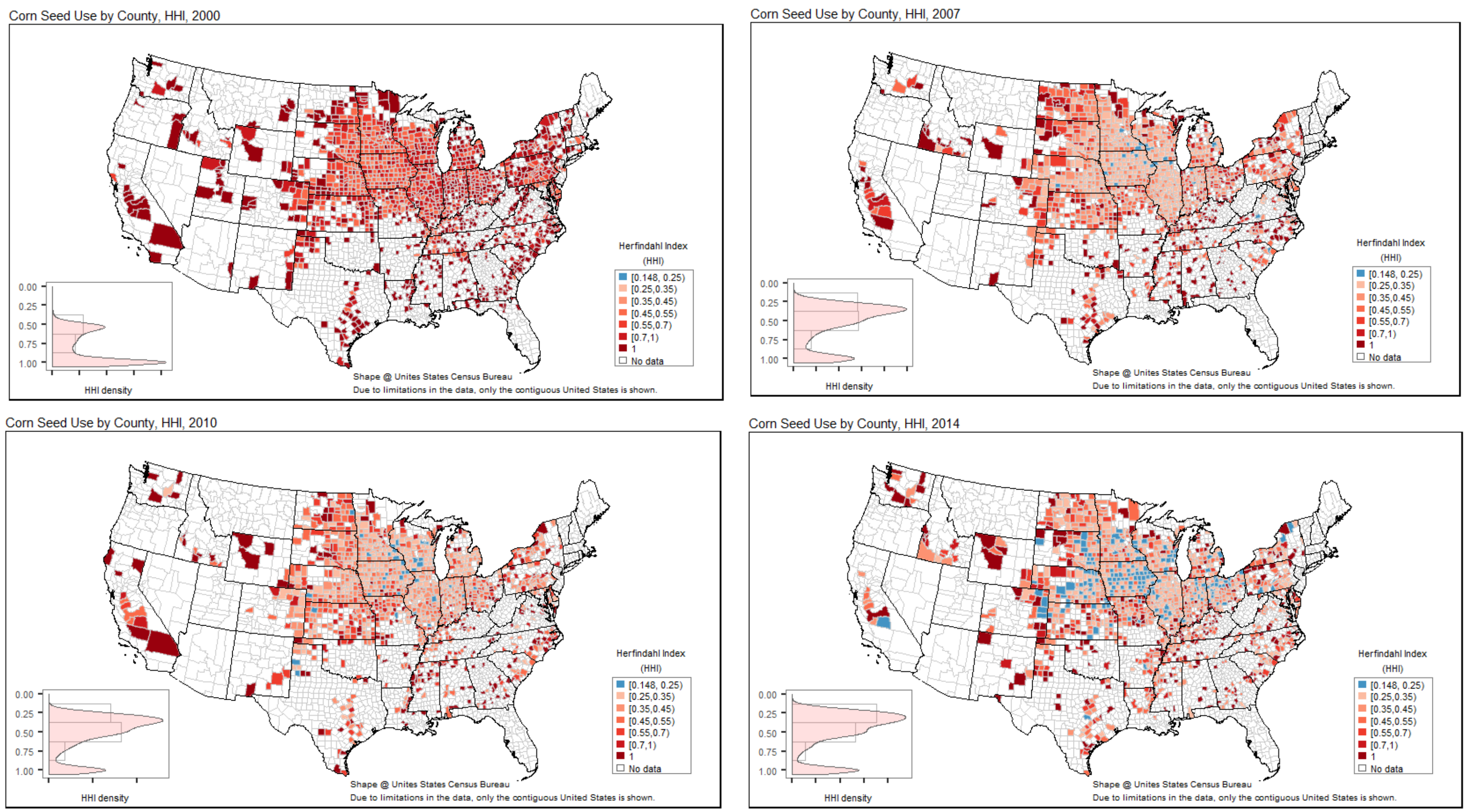


Figure4 Corn Seed GE Trait Adoption in the U.S. Market

---- HHI Index of Seed Type; Computed from GfK Trait Track data

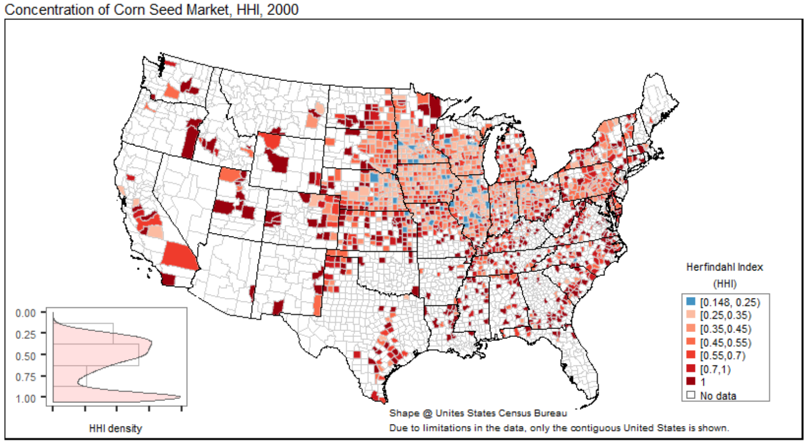


Note: the seed types used in the map are groups of seed products with same number of traits.

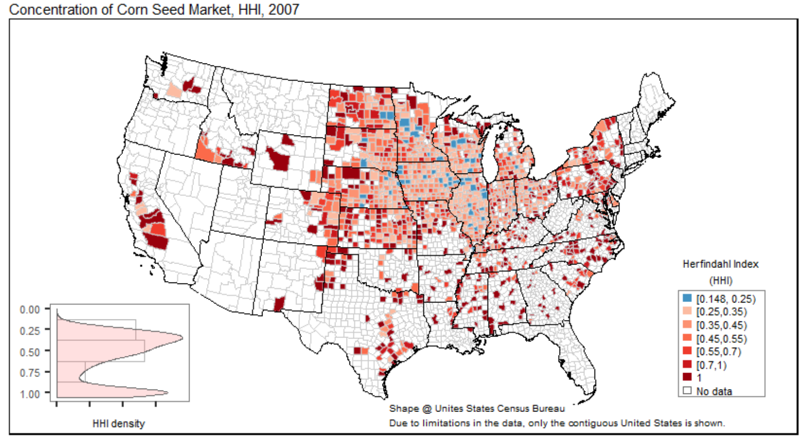
Figure 5 Corn Seed Market Concentration in the U.S. Market

---- HHI Index of Seed Company; Computed from GfK Trait Track data

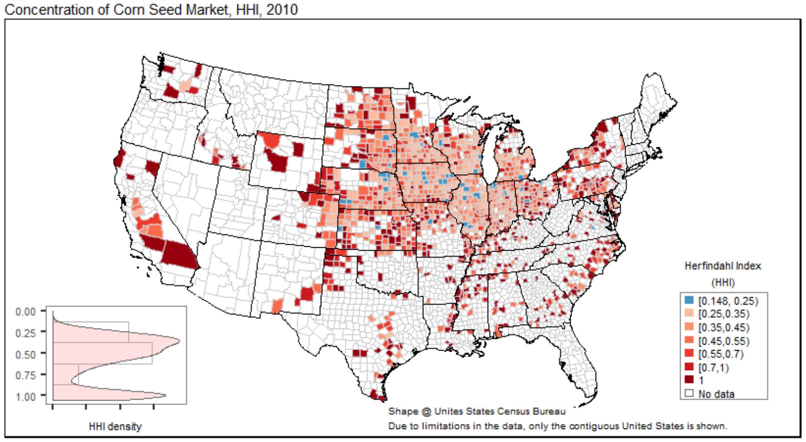
Concentration of Corn Seed Market, HHI, 2000



Concentration of Corn Seed Market, HHI, 2007



Concentration of Corn Seed Market, HHI, 2010



Concentration of Corn Seed Market, HHI, 2014

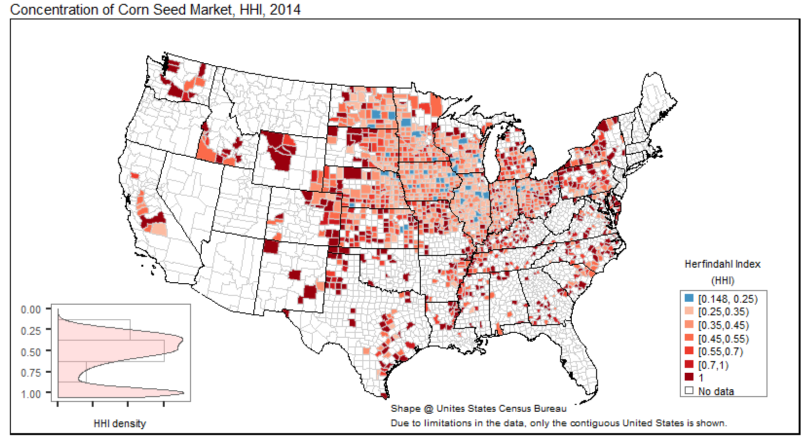


Figure 6 Seed Company Market Share

---- Computed from GfK Trait Track data

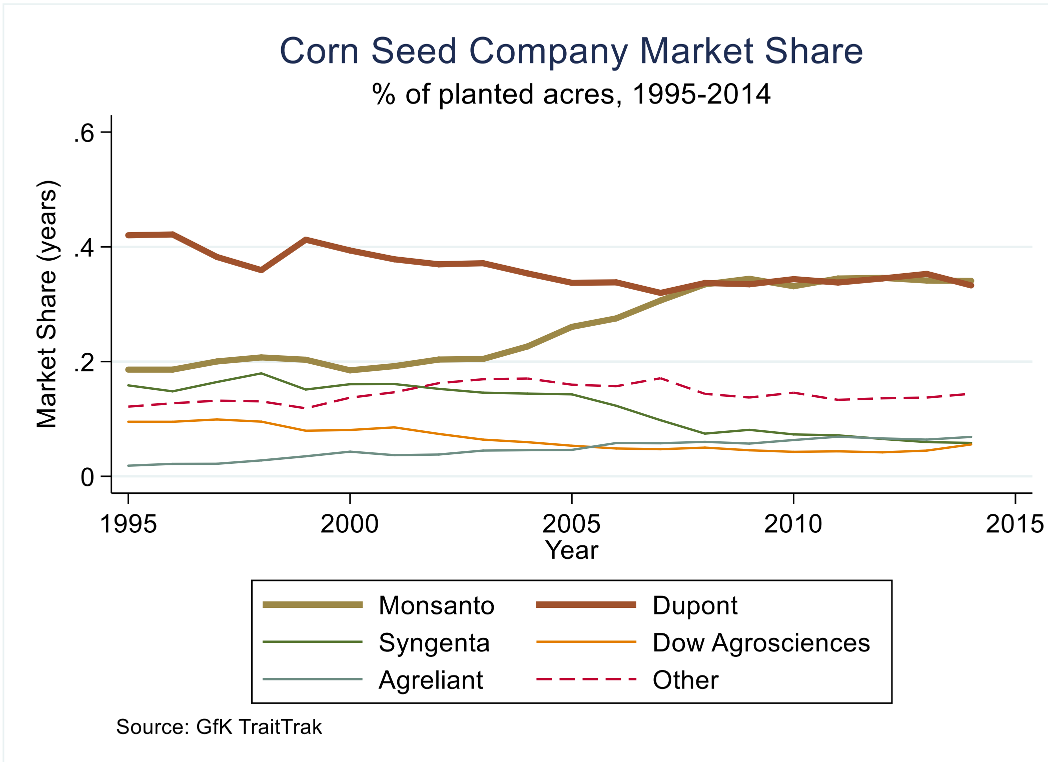


Figure 7 Inflation Adjusted Corn Seed Prices

---- Computed from GfK Trait Track data

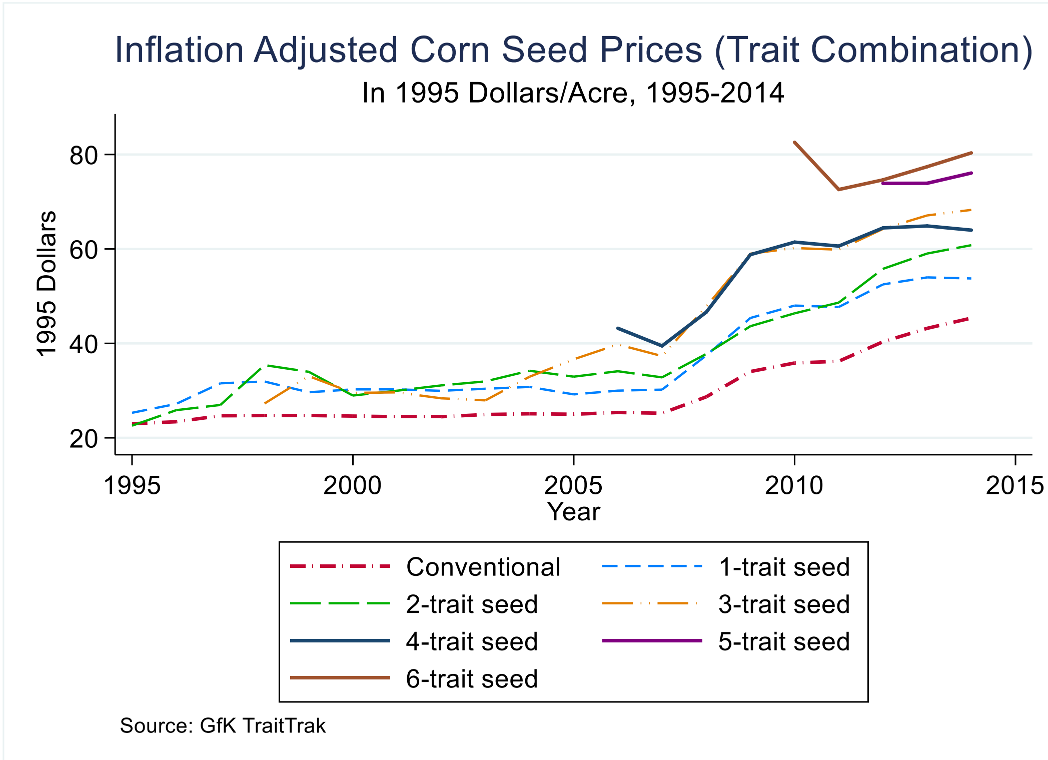


Figure 8 Map of Core and Fringe Regions of U.S. Corn Belt

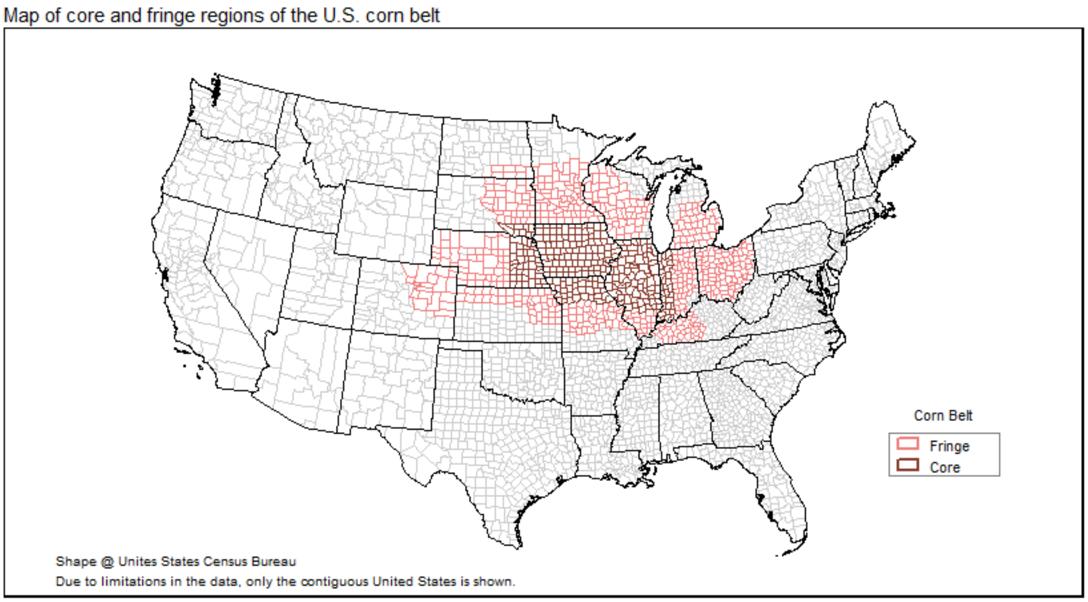


Figure9 Map of Farm Resource Regions of U.S. Corn Belt