Effect of Prices, Traits and Market Structure on Corn Seeding Density

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Short Abstract

Recent agronomic research finds that economically optimal seeding densities have likely increased for many Midwestern corn farmers as a result of genetic improvements including new GM traits such as Bt corn and herbicide tolerance. We derive a per acre demand model for hybrid seed corn to examine the determinants of corn seeding densities and estimate the model using a large data set of individual farmer seed corn purchases. Current results identify factors other than prices affecting farmer corn seeding densities. Among these factors are the GM trait of the seed corn, measures of the local seed corn market structure, seed purchase source and intended end use. We interpret these effects in terms of information effects—farmers with more/better access to the latest agronomic research indicating that recommended seeding densities should be increased tend to plant corn at higher densities.

Key Words: hybrid seed corn, Bt corn, herbicide tolerance, Herfindahl index, corn borer, rootworm, hyperbolic yield model.
JEL Codes: D2, D21, Q1, Q12.

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Introduction

The U.S. seed industry and public researchers have been at the heart of the genetic progress stimulating large productivity improvements in US agriculture. Over the last century, plant breeding has generated significant genetic improvements and higher crop yields. For example, Duvick (1992) estimates that plant breeding accounts for 59% of US crop yield gains since 1930 and about half for corn (Duvick 2005). A contributing aspect of these gains for some crops has been breeding for performance under higher planting densities, especially for corn (Evans and Fischer 1999; Tokatlidis and Koutroubas 2004; Tollenaar et al. 2006). Recent developments in biotechnology have created new opportunities for genetic improvements and have enabled commercialization of genetically modified (GM) crops with specific, desirable traits not possible using traditional breeding techniques (Gepts 2002; Moose and Mumm 2008). As a result, farmers have rapidly adopted GM crop varieties since widespread commercialization in 1996. By 2008, 80% of US corn acres and 92% of US soybean acres were planted with GM seeds (USDA-NASS 2008). Globally, in 2008 GM crops were grown commercially in 25 countries and planted on a total of 309 million acres (8% of all cropland) (James 2008).

Improved management and breeding for improved performance under higher planting densities is an important aspect of the yield increase for corn (Tokatlidis and Koutroubas 2004; Egli 2008). Indeed, the typical planting density for corn has increased from about 3 plants per square meter in the 1930s to around 7 plants in the 1990s (Duvick et al. 2004). The introduction of GM traits has continued this trend. Researchers have examined how some GM traits affect yield potential under different plant densities (Stanger and Lauer 2006; Singer et al. 2003). For example, Stanger and Lauer (2006) found that in Wisconsin, the plant density with maximum yield potential is about 2,300 plants per acre higher for Bt corn[1] controlling European corn borer (ECB) than for conventional non-Bt corn. Singer et al. (2003) found evidence suggesting that Bt corn hybrids are more productive than non-Bt hybrids as the plant density increases.

While the relation between plant density and yield is a technical issue for agronomists, for farmers, plant density and yield is an economic decision. Farmers must balance the yield benefits of higher seeding densities with the increased seed costs these higher densities imply. Furthermore, if the corn yield response to plant density differs for GM and non-GM hybrids, not only does the tradeoff between the yield benefits and seed costs need to account for this difference, but also the for higher cost of GM seeds. Agronomists have examined this tradeoff using experimental plot data. Stanger and Lauer (2006) found that corn with the corn borer Bt trait had a higher plant density for maximum yield, but after accounting for the higher cost of the Bt seed corn, the economically optimal seeding density was the same for Bt and non-Bt corn under their corn and seed price assumptions. However, Lauer and Stanger (2006) developed a method for Wisconsin farmers to determine the economically optimal planting density based on their own seed costs and expected corn price, which under many assumptions implies different economically optimal seeding densities for Bt and non-Bt hybrids. Besides these and similar studies based on experimental plot data, we are unaware of any economic studies documenting and/or examining farmers' actual behavior regarding corn planting densities. Hence, our study aims to fill the information gap between agronomists and economists by using data on actual US farmers' corn seed purchase and planting density decisions.

Besides changes in seed breeding technology, the U.S. seed industry has also restructured. The development and diffusion of hybrid corn starting in the 1930s transformed the US seed

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[1] Corn with genes from the bacterium *Bacillus thuringiensis* (Bt) so that insecticidal proteins are present in its tissues to control insect pests such as European corn borer and western corn rootworm (Steffey et al. 1999).

industry into a private industry with many small local seed companies (Duvick, 1998). However, with the exception of hybrids, few companies had proprietary rights over plant varieties. Beginning in the 1980s, with advances in breeding technology (including biotechnology) and legal changes regarding intellectual property protection of life forms, many small seed companies left the market and the seed industry today is dominated by a few large companies (Fernandez-Cornejo 2004).

This shift to a more concentrated seed industry raises questions about farmer decisions regarding technology adoption and planting density in the presence of market power held by biotech and seed companies. A seed company with greater market power likely has more resources to devote to agronomic research regarding the best use of its technology (such as seeding density) and to educating farmers when introducing new traits. This fundamental agronomic research and technology development and ability for widespread communication is important in the seed corn industry, with the rapid commercialization of new GM traits and rapid turnover of varieties. However, seed varieties adapted to local conditions are important to many growers and, since many smaller regional seed firms vanished with increased market concentration, market power effects may work in the opposite direction. Compared to a giant multinational seed firms, smaller seed companies may have an advantage in breeding varieties for local conditions and in identifying agronomic practices (such as seeding density) for optimal performance of these hybrids, plus may devote more effort to maintaining a close relationship with their customers for effective transmission of this localized knowledge. Our analysis of farmer seeding density decisions takes into account market structure effects to allow for empirical examination of this issue.

In the remainder of the paper we first present a conceptual framework of an expected profit maximizing farmer choosing the corn seed planting density with a hyperbolic yield function. The model derives a per acre demand equation for seed corn depending on seed cost, output price, GM trait, and other factors. Next, we describe the data used in this study and the U.S. seed corn market, and then we present our econometric model and empirical findings. Our primary conclusion is that many of the variables we find with significant effects on seeding density can be interpreted as proxies for information effects—farmers with more/better access to the latest agronomic research indicating that recommended seeding densities should be increased tend to plant corn at higher densities.

Conceptual Model

We assume that farmers make their decisions sequentially. First, farmers choose how many acres of each hybrid to plant, including GM and non-GM varieties. Next, based on these choices, farmers choose the seeding density for each hybrid. For the analysis here, we model only this final choice, the seeding density, taking the acreage allocation and hybrid adoption decisions as given. U.S. farmers typically order corn seed well in advance of planting, commonly in November and December of the year previous to planting. At the time of planting, some adjustments are possible, but purchasing additional seed to increase acreage or seeding density may be possible for low-demand hybrids and reimbursed returns of unused seed are not common. The only common adjustment is to exchange purchased seed for shorter maturity hybrids when weather conditions delay planting.

We assume farmers choose the corn seed planting density to maximize expected net returns, using a hyperbolic yield model for expected crop yield as a function of the planting density (Cousens et al 1987; Jasieniuk et al. 2001; Freckleton and Watkinson 2001):

(1) $$Y = \frac{Bd}{1+\left(Bd/A\right)},$$

where Y is expected corn yield (bu/ac), d is the planting density (seeds per acre), parameter $B > 0$ is the initial slope at a density $d = 0$ and parameter $A > 0$ is the asymptotic (maximum) yield. Different hybrids may exhibit different agronomic properties, which here imply different values for parameters A and B in yield equation (1). For corn hybrid i, farmers choose the planting density d_i to maximize expected per acre profit π_i (\$/ac):

(2) $$\pi_i = p\frac{B_i d_i}{1+\left(B_i d_i / A_i\right)} - r_i d_i - K_i .$$

Corn from different hybrids (GM and non-GM) is priced homogeneous at price p (\$/bu), while hybrid seeds of different types are sold at hybrid-specific prices r_i. Finally, all other input costs are K_i, which may vary across hybrid types—for example, if a farmer uses Bt corn, insecticide costs may be lower.

The optimal planting density, or equivalently, the per acre demand for corn seed type i, is defined by the first order condition:

(3) $$\frac{B_i\left(1+\frac{B_i d_i}{A_i}\right)-\frac{B_i}{A_i}B_i d_i}{\left(1+\frac{B_i d_i}{A_i}\right)^2} = \frac{r_i}{p} .$$

The yield function is concave, and thus the second order condition satisfied, if $A_i > 0$ and $B_i > 0$. Using the quadratic formula to solve equation (3) for d_i gives

(4) $$d_i^* = -\frac{A_i}{B_i} \pm \frac{A_i}{\sqrt{B_i}}\left(\frac{r_i}{p}\right)^{-\frac{1}{2}} .$$

Since $A_i > 0$ and $B_i > 0$ and d_i^* must be non-negative, we use the positive root, so that:

(5) $$d_i^* = -\frac{A_i}{B_i} + \frac{A_i}{\sqrt{B_i}}\left(\frac{r_i}{p}\right)^{-\frac{1}{2}} = \alpha_{0i} + \alpha_{1i} z_i ,$$

where $z_i = \left(\frac{r_i}{p}\right)^{-\frac{1}{2}}$, $\alpha_{0i} = -\frac{A_i}{B_i}$, and $\alpha_{1i} = \frac{A_i}{\sqrt{B_i}}$.

Equation (5) suggests that farmer seed density decisions are related to the relative prices of corn and seed through the parameters *A* and *B*. Not only do these yield parameters likely differ by hybrid type, but also by location due to differences in solar radiation, temperature, rainfall, soil, and similar. Furthermore, these parameters likely vary across time, as regular hybrid improvements have led to steady increases in corn yields around the U.S. (Egli 2008).

Note that estimating this model with behavioral data from actual farmer planting decisions (as opposed to experimental plot data) will not identify the "true" production function parameters, but rather the parameters values for the hyperbolic yield model that farmers are implicitly using when making their seed density decisions. These "perceived" parameters for different seed types depend on farmers' information sets and likely vary due to differential marketing and education efforts by seed companies and local Extension programs, as well as a variety of other factors. Hence we revise the model to incorporate the effect of various factors on the "perceived" production function parameters.

Since breeders and farmers seem to focus more on maximum potential yield (*A*) than on the initial yield gain for the first drop of seeds planted (*B*), we refine the model to allow the production function parameter *A*, but not the initial slope *B*, to depend on covariates **X**,

$$Y = \frac{Bd}{1 + \left(Bd / \left[A + \boldsymbol{\gamma}\mathbf{X}\right]\right)}, \tag{6}$$

where $\boldsymbol{\gamma}$ is a coefficient vector conformable to the covariate matrix **X**. Repeating the optimization process using equation (6) gives:

$$d_i^* = -\frac{A_i + \boldsymbol{\gamma}_\mathbf{i}\mathbf{X}}{B_i} + \frac{A_i + \boldsymbol{\gamma}_\mathbf{i}\mathbf{X}}{\sqrt{B_i}}\left(\frac{r_i}{p}\right)^{-\frac{1}{2}}. \tag{7}$$

Next, define a hybrid type indicator variable $D_i = 1$ if hybrid is type i and zero otherwise, then rewrite equation (7) more generally as

$$(8) \qquad d^* = -\sum_i \frac{(A_i + \boldsymbol{\gamma}_\mathbf{i}\mathbf{X})}{B_i} D_i + \sum_i \frac{(A_i + \boldsymbol{\gamma}_\mathbf{i}\mathbf{X})}{\sqrt{B_i}} D_i \left(\frac{r_i}{p}\right)^{-\frac{1}{2}} .$$

Next, expand the parentheses in the numerators and define new coefficients to write

$$(9) \qquad d^* = \sum_i \alpha_{0i} D_i + \sum_i \alpha_{1i} D_i z_i + \sum_i \boldsymbol{\eta}_\mathbf{i}\mathbf{X} D_i + \sum_i \boldsymbol{\theta}_\mathbf{i}\mathbf{X} z_i D_i ,$$

where again $z_i = \left(\frac{r_i}{p}\right)^{-\frac{1}{2}}$, $\alpha_{0i} = -\frac{A_i}{B_i}$, and $\alpha_{1i} = \frac{A_i}{\sqrt{B_i}}$, and now $\boldsymbol{\eta}_\mathbf{i}$ and $\boldsymbol{\theta}_\mathbf{i}$ are coefficient vectors conformable to the covariate matrix $\mathbf{X}$. Thus, the model now includes two new terms that vary with the covariate matrix: a trait-specific intercept shifter $\boldsymbol{\eta}_\mathbf{i}\mathbf{X}$ and a a trait-specific slope shifter $\boldsymbol{\theta}_\mathbf{i}\mathbf{X}$. If the covariates do not affect the farmers' perceived yield function, the estimated coefficient vectors will be insignificant.

Seed Corn Purchase Data

Our analysis relies primarily on an extensive data set of individual farmer seed corn purchases. An agricultural marketing firm, dmrkynetec (DMR), collected the data from a stratified sample of U.S. corn farmers via a telephone survey annually from 2000 to 2007. The survey provides detailed information for individual seed corn purchases, including corn acreage, specific hybrid purchased, seed planting density, and seed price, as well as the purchase source and intended use for the corn. Other than the state and county of the farm, the data included no social or demographic information concerning the farmer. On average about 40-50% of the farms surveyed each year remain in the sample for the next year. For 2000-2007, the DMR data contains 168,862 observations on individual seed corn seed purchases from 279 USDA crop reporting districts (CRD) in 48 states. A total of 38,617 farms were surveyed during 2000-2007, with each farm on average purchasing four to five different seed varieties each year.

The two major types of GM-traits in the U.S. seed corn market are insect resistance (IR) and herbicide tolerance (HT). IR traits focus on controlling damages from two groups of insect pests: European corn borer (ECB) and other stalk boring lepidopteran pests, and corn rootworms (RW) and other coleopteran pests in the soil (Steffey et al. 1999). Both types of IR corn are Bt corn, with different seed/biotech companies commercializing different events that utilize different Bt proteins for insect control. Examples include Monsanto's YieldGard® hybrids, Pioneer/DuPont/Dow AgroScience's Herculex® hybrids, and Sygenta's AgriSure® hybrids. HT seed corn has traits so that the corn plant is resistant or very tolerant to a specific herbicide, and thus farmers can apply the relevant herbicide to the field to control weeds without damaging the HT-traited crop (Duke 1996). Examples include Monsanto's Roundup Ready® hybrids and Bayer CropScience's LibertyLink® hybrids. The DMR data of each seed corn purchase allow identification of which specific hybrid associated traits was purchased, but data use restrictions that were part of the purchase agreement do not allow reporting data or summaries that identify specific company products. Hence, we categorize all hybrids into general types, such as corn borer Bt, rootworm Bt, or HT, and do not differentiate by company. Thus, if a farmer purchased four different hybrids—two conventional and two different hybrids with HT—the purchase data was aggregated into two observations, one for the conventional seed and one for the HT seed.

Some GM seeds contain only one of these traits. However, companies have increasingly been commercializing hybrids with multiple traits ("stacks") that contain two or more different GM traits, such as corn borer and rootworm Bt corn, or Bt corn combined with an HT trait. More recently, triple and quadruple stacks have become available. Figure 1 uses the DMR data to illustrate farmer adoption of GM corn and the trend towards hybrids with multiple traits from 2000 to 2007. By 2007, conventional seed constituted only about 20% of the seed corn market, while double stacks were the most common GM seed type purchased with about a 30% market share. Triple and single stacks each had a larger share than conventional corn in 2007, each with almost a 25% market share, but the market share for single stacks has been decreasing since 2005. Quadruple stacks were introduced in 2006 and reached a 3% market share in 2007.

For this study, we focused on the Corn Belt and kept only those observations from the 12 states in the north central U.S. (IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD, and WI) with a total of 79 crop reporting districts. We also dropped all observations reporting an intended use of the harvested corn for seed corn or for human food. Finally, we dropped all observations for stacked hybrids with only a few observations, leaving nine different types of "traited" corn and a final total of 136,889 observations of individual seed corn purchases. Table 1 reports the nine hybrid trait types, plus various descriptive statistics for the average seeding density. Table 1 shows that about half of the seed corn purchases are for conventional (non-GM) seed. Among the GM seed, most purchases are for corn borer Bt, HT, and corn borer Bt stacked with HT. Considering the average seeding densities in Table 1, HT is the lowest and then conventional seed, with GM seed purchases containing a rootworm Bt corn trait having among the highest seeding densities. The standard deviations of the seeding densities are around three to four thousand, with wide range between the minimum and maximum seeding density, especially for conventional seed.

Table 2 reports average seeding densities by year for conventional and GM hybrids, plus the total number of different corn hybrids purchased and the percentage of these hybrids that were GM. The DMR data show the steady increase in average seeding densities for both conventional and GM hybrids over this period and indicate that for most years, the average GM seeding density is slightly higher than for conventional hybrids, consistent with Table 1. Table 2 also indicates the rapid introduction of GM hybrids during this period—the percentage of all hybrids that were GM hybrids increase from 26% in 2000 to 75% in 2007.

Econometric Estimation and Results

As derived, equation (9) is a structural equation reflecting the determinants of farmers' seeding densities under heterogeneous farm and market conditions. The dependent variable is the observed seeding density for each seed corn purchase after aggregating them to the nine different traits reported in Table 1 and indexed by the subscript i in equation (9). The primary regressor is the seed to corn price ratio r_i/p, where r_i is the seed price ($/bag) for trait i and p is the expected corn price ($/bu). We use the per bag seed price, as the per acre seed price is endogenous to the seeding density chosen. For the expected corn price p, we use the announced base price for the CRC crop revenue insurance policy for corn in each year. This price is the average of the daily settlement price for the September corn futures contract on the Chicago Board of Trade for December 15 to January 14. The USDA Risk Management Agency widely announces this price in mid-January as farmers use it to make their crop insurance decisions. As indicated in equation (9), the actual regressor is $z_i = (r_i/p)^{-½}$ as derived in the conceptual model. Table 3 reports summary statistics for the seed price and the price ratio r_i/p.

Estimation also includes several covariates as trait-specific intercept and slope shifters. Table 3 reports summary statistics for the main variables used to construct these covariates. For each farmer in the survey, we are able to determine the total number of corn acres planted as a proxy for farm size. Table 3 shows that the average farmer planted almost 600 acres of corn, but that this planted acreage varied widely among the surveyed farmers. In addition, we used the same information to construct a regressor that is the percentage of each farmer's total seed purchased that is GM. These variables serve as proxies for socio-demographic variables, such as income, education, and age, plus they may capture learning or information effects.

To control for geographic effects, we use the latitude and longitude of the center of the county where the surveyed farm was located. Latitude largely determines the solar radiation (light) available for plant growth and so is important in planting density decisions. We use longitude to capture the general rainfall gradient that exists when moving from east to west across the 12 states in the data set, since moisture availability also impacts planting density decisions. Latitude and longitude also capture temperature and other climatic effects.

For market structure, we construct the traditional Herfindahl-Hirshman Index (HHI) for seed corn sales at the crop reporting district level. The HHI is commonly used in the analysis of the exercise of market power (e.g., Whinston 2008). In addition, we also construct the seed corn market share at the crop reporting district level of each of the four large integrated biotech-seed companies: Pioneer/DuPont, Monsanto, Syngenta, and Dow AgriScience. In addition, we interact these four acreage shares with a binary indicator variable for all brands that each company owns, e.g., Monsanto's acreage share multiplied by $C_i = 1$ if the seed corn purchase is of brands own by Monsanto and $C_i = 0$ otherwise. However, due to data restrictions, we do not report any summary statistics for these variables and, when we report regression results, designate the companies in no particular order as company I, II, III, and IV.

Among the covariates we also include a time trend to capture advances in hybrid and genetic technology during study period. In addition, we use binary indicator variables for the seed purchase source and intended end use to capture possible information effects arising from better access to the latest research information from seed companies or end users. For example, farmers who are also seed dealers may be more experienced and informed compared to farmers who are not. The survey included 16 different purchasing sources, but since farmers purchase most seeds through “Farmer who is a dealer or agent” (33%), “Direct from seed company or their representatives” (29%), and “Myself, I am a dealer for that company” (16%), we group the remaining 13 sources into “Other” (21%). The survey also included several intended end use categories, such as ethanol plant, feed mill, export, and silage, as well as simply grain or multiple uses. We also include state dummy variables to capture information and learning effects arising from differences in extension programs and institutional heterogeneity among the states.

Based on this discussion, we estimate the seed density decision for a typical farmer as:

$$d^* = \sum_i \alpha_{0i} D_i + \sum_i \alpha_{1i} D_i z_i + \sum_i \boldsymbol{\eta}_\mathbf{i} \mathbf{X} D_i + \sum_i \boldsymbol{\theta}_\mathbf{i} \mathbf{X} z_i D_i + \boldsymbol{\beta} \mathbf{L} + \varepsilon \,, \tag{10}$$

where again **X** is a vector of relevant covariates including HHI, latitude, longitude, year time trend, and total corn acres; **L** is vector of variables for trait-invariant effects, including indicator variables for state, seed purchase source and intended end use, plus the CRD-level market share of the top four biotech/seed companies and the GM acreage share for each individual farmer; and finally ε is a mean zero and constant variance error term. Note that equation (10) implies that the variables in **L** have trait-invariant effects on farmers’ seeding density decisions.

The DMR data suggest that each farm purchases on average four to five different seed varieties, with some large farms actually purchasing up to 30 different varieties in a single year. We expect unobserved farm-specific factors affecting seeding densities to be similar within a farm (although they may differ across farms), which suggests that the variance of the error term in equation (10) may exhibit heteroscedasticity, with clustering at the farm level. A Breusch-Pagan test found strong evidence against homoscedasticity, and so we rely on heteroscedastic-robust standard errors under clustering at the farm level in estimating equation (10), which we implement during estimation in STATA. Table 4 reports estimation results. Given the large number of estimated coefficients, we discuss the intercept effects first, and then the slope effects.

Intercept Effects

In terms of intercept effects, three GM-traited seeds, HT, rootworm Bt, and corn borer Bt stacked with HT, show a statistically significant difference in planting density relative to conventional corn, with each planted at higher densities. Note that these are only partial effects of traits on seeding density, i.e., only on the intercept and not including effects from any of the estimated interaction terms. We discuss a global assessment of seed trait effects later. Wald tests of pair-wise comparisons among traits suggest that the rootworm Bt trait may differ from the other traits in some fundamental way (significantly different in all comparisons at 1% level). Almost all other traits are similar to each other at the 5% level.

Total corn acreage planted (a proxy for farm size) is positive and statistically significant across all seed traits. Our results imply that larger farms tend to plant more seeds per acre, with the effect seeming to differ across traits. In general, the farm size effect is largest for conventional seed, followed by single-traited seed, and then stacked-trait seed. We interpret these results as evidence that larger farmers have better access, or are more willing to trust, extension programming and other research-based information sources recommending that farmers plant corn at higher densities than most farmers currently are (Fee 2009; Lauer and Stanger 2006). Also, larger farms may be less capital constrained and so more willing to spend the higher costs usually implied by higher planting densities.

In terms of purchasing source, if a farmer is a seed dealer purchasing seed from his/her own dealership, then the farmer tends to plant at higher seed densities compared to those purchasing seed from other sources. Moreover, Wald test results suggest that if farmers purchasing seed directly from the seed company tend to plant at higher densities compared to those purchasing from another farmer who is also a seed dealer. These results seem to support our hypothesis of an information/education effect on farmer plant density decisions. Farmers who are also seed dealers likely receive or seek additional training and information regarding the latest agronomic research concerning corn and seeding, and therefore make slightly more informed (and thus different) planting density decisions compared to others. Similarly, farmers who purchase directly from the seed company may receive similar or more information compared to those purchasing from another farmer dealer (the information has one less intermediary to flow through).

Farmer planting density decisions also depend on the intended end use of their harvested corn. Farmers planting corn for silage (either solely or a dual purpose grain/silage hybrid) tend to use fewer seeds per acre. These farmers likely manage integrated crop/livestock operations and are less specialized in grain production. However, farmers planting for corn for export purposes or for ethanol production tend to plant more seeds per acre. These farmers likely are more specialized grain farmers, and so more likely to seek out and use the latest agronomic information. Also, farmers who allocate a larger share of their corn acres to GM corn hybrids tend to plant more seeds per acre. As more intense users of the latest seed technologies, such farmers likely are more informed regarding the latest corn agronomic research.

Location and Time Effects

Seeding densities vary across these states, due to climatic differences, as well as cultural, economic, and institutional differences. Trait-invariant state indicator variables capture many of these effects, while latitude and longitude capture the climatic differences. Relative to Wisconsin farmers, farmers in Illinois, Indiana, Iowa, Minnesota and Ohio use more seeds per acre, while farmers in the other states use fewer. Moving from south to north (the latitude effect), farmers generally use more seeds per acre for all trait types except for the RW Bt corn (negative and statistically significant coefficient). Moving from east to west (the longitude effect), farmers plant statistically significantly more seeds per acre for a few traits (conventional seed, corn borer Bt and triple stacks), but most of the longitude coefficients are insignificant. Finally, the time trend effect is positive and statistically significant only for HT and triple stack corn borer Bt plus two HT traits. Also, since triple stacks were introduced in 2006, the data only contain observations for two years.

Market Concentration Effects

The model incorporates market share information at the CRD level using the traditional Herfindahl indexes (HHI), as well as the market share of the four largest integrated biotech/seed companies. If the market concentration is mostly driven by the major integrated biotech/seed companies, we would expect multicollinearity between the two sets of variables. However, since we define the market at the CRD level, we may expect very different local market players across regions. A local firm may not be "big" in terms of its national market share, but could be a dominant player in its local regional market. In this case, multicollinearity should not be a problem. Testing for correlation between the two variables did not suggest a serious multicollinearity problem, consistent with our regression results. Here, we discuss the partial effects of market concentration, withholding a global assessment until later.

Market concentration effects as captured by the HHI are positive when statistically significant, which is the case for corn borer Bt corn and corn borer Bt stacked with HT. For these two traits, the more concentrated the local market is, the more seeds farmers plant per acre. Market concentration effects as captured by the biotech companies' market shares are mixed.

For all companies, the larger their market share in a CRD, the fewer seeds farmers plant per acre in that CRD. However, for three companies (I, II, and III), if farmers purchase seeds from one of these companies, this negative market share effect is offset and farmers tend to plant more seeds per acre. For company IV, the negative market share effect is reinforced if the farmer also purchases seed from company IV. The implication is that in a CRD with the seed corn market dominated by the large biotech seed companies, farmers who buy seed from these large companies tend to plant more seed per acre, while farmers who do not buy seed from one of these companies tend to plant fewer seeds per acre.

Our interpretation of these results is again in terms of information effects. Agronomic research and data suggest that farmers are planting corn at less than economically optimal densities (Stanger and Lauer 2006; Lauer and Stanger 2006; Fee 2009). We think that market concentration and market shares serve as proxies for how well the seed companies can communicate with farmers purchasing their seed. In markets with few firms, the companies can devote more attention to communicating the latest agronomic research concerning recommended corn seeding densities with their buyers. In markets with many firms, the farmers do not hear a consistent message or do not trust it, or think it does not apply to the brand of seed they buy. Furthermore, in more competitive seed corn markets, companies may not want to emphasize the benefits of planting seed at higher densities, as doing so costs farmers more per acre and companies may be concerned about losing sales to “lower cost” competitors.

Slope Effects

As indicated in equations (5) and (9), our model suggests that the price ratio coefficients should be positive because they implicitly define the ratios of the production parameters A and B which are positive. The regression results are consistent with this prediction, except for the rootworm Bt corn trait, where the price ratio effect is negative and statistically significant. However, the effective value of the production parameter *A* also depends on the other covariates (see equations (6) through (9)), and so is positive for most reasonable values of the covariates.

The market concentration effect on the slope as captured by the HHI is statistically significant only for the corn borer Bt corn (negative) and the corn borer/rootworm Bt corn (positive). These results suggest that market concentration generally does not affect the seeding density elasticity, however, when it does, it does differently across seed types. Other variables affecting the slope include the time trend, latitude and longitude. Similar to the market concentration effect, these factors do not seem to have a significant impact on the slope, and when they do, the impacts differ across traits. The time trend slope coefficients are insignificant for all traits except for HT and corn borer Bt stacked with two HT traits (both negative). Latitude has a slope effect only for conventional seed (negative) and rootworm Bt (positive). Longitude also has a significant slope effect for only three traits: conventional, corn borer Bt and corn bore/rootworm Bt with HT (all negative).

The general implication is that many of the covariates have insignificant effects on how the planting density responds to the seed price (normalized by the expected price of corn). However, before making such a conclusion, we note that the statistical significance of the marginal effects are generally of more economic interest than the significance of the specific coefficients. The marginal effects are the global effect of each covariate on the seeding density, both the intercept and slope effects, after working through all the interaction terms. The case is similar to demand studies, where the interest is in the significance of the elasticities, which are functions of the estimated coefficients, not in the significance of the coefficients themselves. Unfortunately, for our study, time constraints have prevented us from implementing the numerical procedures needed to calculate the marginal effects and their significance, and so we leave that to future work.

Conclusion

Recent agronomic research has found that economically optimal seeding densities have likely increased for many Midwestern corn farmers as a result of genetic improvements and the addition of new bioengineered traits such as Bt corn and herbicide tolerance. We derive a per acre demand model for hybrid seed corn assuming expected profit maximization and a hyperbolic yield function to examine the determinants of corn seeding densities. We empirical implement the model using a large data set of individual farmer seed corn purchases. Current results identify many factors other than prices that affect farmer corn seeding densities. Among these factors are the different GM traits of the seed corn and measures of the local seed corn market structure (Herfindahl-Hirschman index, integrated biotech/seed company market shares), as well as purchase source and intended end use. We interpret these and some of the other effects in terms of information effects—farmers have differential access to the latest agronomic research, or assign differing levels of credibility to the information sources, and farmers with more/better access to the latest agronomic research indicating that recommended seeding densities should be increased tend to plant corn at higher densities.

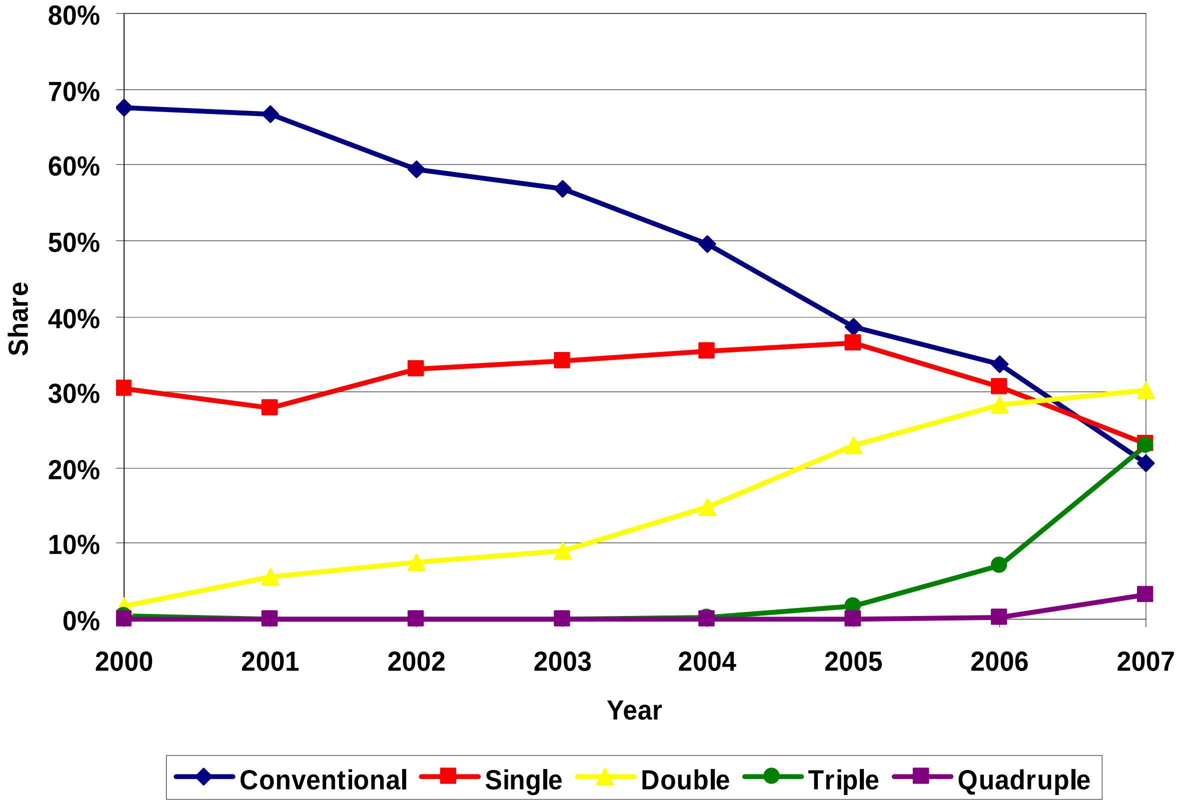

Figure 1. Corn seed adoption rates (expressed as acreage shares) for 2000-2007 for conventional varieties, single stack GM varieties, and multiple stacked GM varieties.

Table 1. Summary statistics for seeding density by hybrid trait across all years 2000 to 2007.

Hybrid Trait	Observations	Mean	St. Dev.	Minimum	Maximum
Conventional	67,912	28,662	3,715	10,000	53,333
Corn Borer Bt (CB Bt)	22,536	29,094	3,669	12,000	50,000
Rootworm Bt (RW Bt)	1,021	29,733	3,374	15,385	37,142
Herbicide Tolerant (HT)	17,636	28,399	4,337	10,811	48,000
CB Bt+ RW Bt	1,359	30,464	2,925	16,000	40,000
CB Bt + HT	18,450	29,279	3,969	11,500	44,148
RW Bt + HT	1,345	30,353	3,371	10,769	40,000
CB Bt + RW Bt + HT	5,079	30,637	3,263	15,135	42,666
CB Bt + HT_1 + HT_2	1,551	29,194	3,978	16,146	40,000
All	136,889	28,904	3,836	10,000	53,333

Table 2. Average corn seeding density for conventional and GM hybrids and number of different hybrids sold by year.

Year	Average seeding density Conventional	GM	Number of Hybrids (% GM)
2000	27,870	28,120	3,218 (26%)
2001	28,080	28,230	3,723 (28%)
2002	28,170	28,490	3,631 (35%)
2003	28,620	28,630	3,501 (40%)
2004	28,760	28,790	3,555 (50%)
2005	29,010	28,970	4,549 (58%)
2006	29,240	29,140	4,879 (66%)
2007	29,160	29,480	5,862 (75%)

Table 3. Summary statistics for other seed corn purchase variables.

Variable	Observations	Mean	St. Dev.	Minimum	Maximum
Seed Price ($/bag)	136,889	99.40	23.47	3.00	230.00
Seed:Corn Price Ratio[a]	136,889	37.11	9.03	1.06	91.63
Total Corn Acres for Farm	136,889	590	614	5	12,000
County Latitude[b]	136,889	41.78	1.91	37.19	46.98
County Longitude[b]	136,889	91.71	4.60	80.75	103.76
Herfindahl-Hirshman Index	632[c]	0.210	0.100	0.080	0.960

[a] Ratio of seed price ($/bag) to expected corn price ($/bu), or r/p in equation (9).

[b] Latitude and longitude for the center of the county in which the surveyed farm is located.

[c] Because the Herfindahl-Hirshman Index is for seed corn sales at the crop reporting district (CRD) level, the maximum number of observations is 79 CRDs x 8 years = 632.

Table 4. OLS regression results[a].

Variable	Coefficient	Standard Error[b]	p Value
Intercept[c]	-19,250	5,531	0.001
Traits			
Corn Borer Bt (CB Bt)	3,491	8,273	0.673
Rootworm Bt (RW Bt)	123,473	34,106	0.000
Herbicide Tolerant (HT)	19,061	8,496	0.025
CB/RW Bt	4,143	32,976	0.900
CB Bt/HT	21,095	9,434	0.025
RW Bt/HT	-6,004	23,694	0.800
CB/RW Bt/HT	-15,511	22,400	0.489
CB Bt/HT/HT	-29,225	25,174	0.246
Corn Acres (1000s) x Trait			
Corn Acres x Conventional	1.019	0.060	0.000
Corn Acres x CB Bt	0.850	0.072	0.000
Corn Acres x RW Bt	0.956	0.180	0.000
Corn Acres x HT	0.999	0.104	0.000
Corn Acres x CB/RW Bt	0.756	0.218	0.001
Corn Acres x CB Bt/HT	0.825	0.078	0.000
Corn Acres x RW Bt/HT	0.368	0.143	0.010
Corn Acres x CB/RW Bt/HT	0.422	0.097	0.000
Corn Acres x CB Bt/HT/HT	0.658	0.194	0.001
Seed Source			
Myself as dealer	221.5	72.068	0.002
Directly from seed company	49.23	53.91	0.361
Other farmer dealer”	-66.31	53.00	0.211
End Use			
Corn gluten plant	384.1	277.01	0.166
Dual purpose grain & silage	-421.2	114.69	0.000
Ethanol plant	134.7	125.75	0.284
Export	664.9	109.35	0.000
Grain only-livestock/poultry	989.0	245.79	0.000
Grain only-other	-184.5	131.76	0.161
Multiple uses	-131.1	79.907	0.101
Silage only	42.12	69.02	0.542
Share of corn acreage as GM	305.7	122.44	0.013
State			
Illinois	756.0	163.9	0.000
Indiana	240.5	188.6	0.202
Iowa	437.6	149.1	0.003
Kansas	-3,500.8	300.4	0.000
Michigan	-730.9	233.1	0.002

[a] 136,889 observations, $R^2 = 0.28$.

[b] Heteroscedastic-robust standard errors estimated in STATA.

[c] Base Case: conventional seed in Wisconsin, other seed source, unknown end use.

Table 4 (continued). OLS regression results.

Variable	Coefficient	Standard Error[a]	p Value
State (continued)			
Minnesota	105.2	166.7	0.528
Missouri	-1,897.9	229.2	0.000
Nebraska	-3,729.8	241.7	0.000
North Dakota	-4,321.9	335.8	0.000
Ohio	1,235.6	216.1	0.000
South Dakota	-5,721.3	247.5	0.000
Latitude x Trait			
Latitude x Conventional	756.4	114.2	0.000
Latitude x CB Bt	450.1	154.2	0.004
Latitude x RW Bt	-1,513.1	749.3	0.043
Latitude x HT	450.1	152.9	0.003
Latitude x CB/RW Bt	534.2	561.0	0.341
Latitude x CB Bt/HT	495.5	159.0	0.002
Latitude x RW Bt/HT	903.2	515.7	0.080
Latitude x CB/RW Bt/HT	886.5	347.5	0.011
Latitude x CB Bt/HT/HT	465.9	468.1	0.320
Longitude x Trait			
Longitude x Conventional	187.9	53.57	0.000
Longitude x CB Bt	265.2	73.59	0.000
Longitude x RW Bt	-50.41	280.9	0.858
Longitude x HT	72.15	81.36	0.375
Longitude x CB/RW Bt	137.2	268.7	0.610
Longitude x CB Bt/HT	78.80	84.91	0.353
Longitude x RW Bt/HT	134.7	258.8	0.603
Longitude x CB/RW Bt/HT	344.9	164.7	0.036
Longitude x CB Bt/HT/HT	407.1	241.8	0.092
Year x Trait			
Year x Conventional	116.1	79.59	0.145
Year x CB Bt	110.8	109.9	0.313
Year x RW Bt	-1,160.1	743.4	0.119
Year x HT	457.5	163.8	0.005
Year x CB/RW Bt	2,036.7	1,304.5	0.118
Year x CB Bt/HT	-40.95	193.9	0.833
Year x RW Bt/HT	961.6	992.1	0.332
Year x CB/RW Bt/HT	-485.8	1,263.1	0.701
Year x CB Bt/HT/HT	2,930.0	1,056.8	0.006
Herfindahl Index x Trait			
HHI x Conventional	4,147	2,731	0.129
HHI x CB Bt	12,484	3,926	0.001
HHI x RW Bt	698.4	19,595	0.972
HHI x HT	5,395	4,394	0.220

[a] Heteroscedastic-robust standard errors estimated in STATA.

Table 4 (continued). OLS regression results.

Variable	Coefficient	Standard Error[a]	p Value
Herfindahl Index x Trait (continued)			
HHI x CB/RW Bt	-21,948	14,522	0.131
HHI x CB Bt/HT	8,692	4,368	0.047
HHI x RW Bt/HT	-7,869	11,402	0.490
HHI x CB/RW Bt/HT	-2,891	7,245	0.690
HHI x CB Bt/HT/HT	-3,370	13,203	0.799
Company Acreage Shares			
Company I share	-791.2	391.2	0.043
Company I share x seed from I	902.4	133.5	0.000
Company II share	-820.6	365.8	0.025
Company II share x seed from II	531.1	175.1	0.002
Company III share	-1,091.3	392.2	0.005
Company III share x seed from III	1,542.3	494.5	0.002
Company IV share	-3,487.6	631.8	0.000
Company IV share x seed from IV	-2,977.0	1,322.2	0.024
Slope (Price) Effects (x $z = (r/p)^{-½}$)			
Conventional	121,801	28,502	0.000
CB Bt	99,736	46,588	0.032
RW Bt	-645,852	217,973	0.003
HT	57,670	42,765	0.178
CB/RW Bt	129,600	213,196	0.543
CB Bt/HT	4,240	50,833	0.934
RW Bt/HT	220,028	146,956	0.134
CB/RW Bt/HT	242,726	137,395	0.077
CB Bt/HT/HT	252,259	145,679	0.083
Price x Herfindahl Index x Trait			
Price x HHI x Conventional	-10,206	15,121	0.500
Price x HHI x CB Bt	-46,568	24,838	0.061
Price x HHI x RW Bt	44,984	127,973	0.725
Price x HHI x HT	-3,853	25,275	0.879
Price x HHI x CB/RW Bt	165,615	90,279	0.067
Price x HHI x CB Bt/HT	-25,239	26,380	0.339
Price x HHI x RW Bt/HT	78,349	69,385	0.259
Price x HHI x CB/RW Bt/HT	51,707	44,312	0.243
Price x HHI x CB Bt/HT/HT	54,980	75,028	0.464
Price x Year x Trait			
Price x Year x Conventional	464.2	421.6	0.271
Price x Year x CB Bt	468.9	651.7	0.472
Price x Year x RW Bt	7,110	4,773	0.136
Price x Year x HT	-1,837	934.8	0.049
Price x Year x CB/RW Bt	-13,690	8,665	0.114

[a] Heteroscedastic-robust standard errors estimated in STATA.

Table 4 (continued). OLS regression results.

Variable	Coefficient	Standard Error[a]	p Value
Price x Year x Trait (continued)			
Price x Year x CB Bt/HT	1,353	1,195	0.258
Price x Year x RW Bt/HT	-6,907	6,304	0.273
Price x Year x CB/RW Bt/HT	3,147	8,855	0.722
Price x Year x CB Bt/HT/HT	-16,980	6,676	0.011
Price x Latitude x Trait			
Latitude x Conventional	-1,931	631.5	0.002
Price x Latitude x CB Bt	10.59	947.6	0.991
Price x Latitude x RW Bt	12,698	4,907	0.010
Price x Latitude x HT	-221.6	883.6	0.802
Price x Latitude x CB/RW Bt	-903.5	3,574	0.800
Price x Latitude x CB Bt/HT	-187.4	968.9	0.847
Price x Latitude x RW Bt/HT	-2,605	3,273	0.426
Price x Latitude x CB/RW Bt/HT	-2,912	2,106	0.167
Price x Latitude x CB Bt/HT/HT	852.6	2,699	0.752
Price x Longitude x Trait			
Price x Longitude x Conventional	-568.8	280.0	0.042
Price x Longitude x CB Bt	-1,082	445.9	0.015
Price x Longitude x RW Bt	707.5	1,807	0.695
Price x Longitude x HT	-412.3	467.0	0.377
Price x Longitude x CB/RW Bt	-262.9	1,747	0.880
Price x Longitude x CB Bt/HT	-116.8	509.7	0.819
Price x Longitude x RW Bt/HT	-833.0	1,611	0.605
Price x Longitude x CB/RW Bt/HT	-1,643	990.4	0.097
Price x Longitude x CB Bt/HT/HT	-1,866	1,412	0.186

[a] Heteroscedastic-robust standard errors estimated in STATA.

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