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A Hedonic Price Analysis of Corn and Soybean Herbicides

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Herbicides account for approximately 2.2% of total farm expenses and are applied to more than 80% of farmland in the USA. The widespread adoption of herbicides contributed to the increased and relatively cheaper productivity of modern intensively managed agricultural systems in developed countries. The present study uses a hedonic framework to analyze the effect of selected attributes on the price of corn and soybean herbicides. Two different empirical models were estimated separately for the two crops. The data include information on 51 herbicides, 27 for corn and 24 for soybean crops used in Kentucky. Findings indicate that efficacy against weeds and crop response (illustrates the potential of an herbicide to injure a crop) of herbicides are significant determinants of their prices. Moreover, some of the environmental statements have an effect on herbicide prices. The study confirms the importance of explicitly including information about herbicides active ingredients and their impacts on plants' physiological cycle as it improved the model fit for corn herbicides and provided results in line with the a-priori hypothesis.

Key words: hedonic price analysis, herbicide pricing, herbicides mode of action, herbicides characteristics

Introduction

The widespread adoption of herbicides after 1950s is one of the major factors in the industrialization of agriculture, contributing to the increased and relatively cheaper food supplies generated by the modern intensively managed agricultural systems. The importance of herbicides in U.S. is undeniable as more than 80% of U.S. farmland is treated with herbicides and this percentage exceeds 90% for some crops such as corn, soybean and sorghum (Gianessi and Reigner, 2007). Furthermore, around $4 billion is spent on these herbicides which accounts for approximately, 2.2% of total farm expenses during 2007 and 2008 (USDA, ERS)

This widespread adoption of herbicides is easily understood from the benefits that their use provides to producers. Specifically, these benefits include reduction in production cost, increase in yields and reduced cultivation practices. Despite those benefits the publicity of harmful effects to the environment, human health and animal welfare associated with improper use of herbicides concerns some consumers, politicians and economists leading to a debate related to herbicide utilization. With considerable amount of money spent on herbicides, and an extensive discussion revolving around their usage quantitative evidence about their price determinants is important in order to better understand the herbicide market.

Although extensive research has been done to analyze the effect of prices, production practices and government programs on farm chemical usage (Lin et al., 1995) the literature examining herbicide pricing is relatively small mainly because of data limitations, especially after USDA-NASS has reduced the amount of data it collects. Beach and Carlson (1993) illustrated that it is possible using hedonic analysis to estimate implicit prices for herbicide attributes. Moreover, they found that water quality and user safety characteristics although significant, are minor determinants in the herbicide selection. Fernadez-Cornezo et al. (2009)

used the hedonic pricing framework to calculate quality and quantity adjusted price indices for herbicides. The authors observed that quality adjusted prices have tailed off sharply in recent years and that quantity indices show a small increase. A different approach was implemented by Owens et al. (1998) who used a double-hurdle model to estimate farmers' willingness to pay for herbicide safety characteristics. Their findings suggest that farmers are more concerned about on farm health and environmental effects than about off farm effects.

The hedonic price framework assumes that the price of a product is a function of the quality and quantity of its attributes. Products with more attractive characteristics are hypothesized to sell at higher prices. Beach and Carlson (1993) illustrated that herbicides, as a product class, satisfy the key assumptions of hedonic prices, namely: i) products differentiated into market oriented outputs, ii) products cannot be rearranged without additional cost and iii) products can be described by a large number of product bundles. Thus, the prevailing market prices of an herbicide can be considered as hedonic prices.

The objective of the present study is to examine the effect of productive and hazardous herbicide characteristics on their prices. Efficacy against grasses and broadleaf weeds, crop response (which illustrates the potential of a herbicide to cause injury to a crop), environmental statements (as a proxy for toxicity), herbicide selectivity, application period and herbicides Mode of Action, defined as the biochemical or physical means by which a herbicide kills plants, are used as quality characteristics. The hedonic pricing framework is applied in order to obtain estimates for the implicit prices and the effects of those characteristics on herbicides prices. Two distinct empirical models, based on different sets of attributes, are estimated separately for corn and soybean herbicides. The data for the herbicides come from four main sources: University of Kentucky extension service publications, USDA, herbicide labels and the Kentucky Farm

Bureau. The main contribution of this study in the literature is the explicit inclusion in a hedonic pricing model of information about chemical interactions between herbicides and plants in the form of Mode of Action.

The findings of the study may act as a guide indicating where manufacturers should focus their research and development efforts in order to achieve higher prices and how to set prices that more accurately reflect the attributes of their herbicides. Last but not least, reliable estimates for the marginal values of different herbicide attributes may help policy makers in their efforts to introduce policies that reduce the negative effects of herbicide usage.

Theoretical Framework

This section includes a review of hedonic modeling which provides the theoretical framework used to investigate herbicides pricing. The hedonic price technique is a method for estimating the implicit prices of the characteristics that differentiate closely related products, in a product class. The development of hedonic pricing models relies on two central assumptions: first, that, products can be differentiated based on their attributes and, second, that consumers select a product because it possesses a number of desired attributes at the prevailing price. Thus, demand for the different attributes can be derived from consumers' willingness to pay for a particular product. Furthermore, observed prices of the differentiable commodity, and its associated set of characteristics, can reveal an implicit price or value for each attribute.

The formal theory of hedonic prices in the context of competitive markets was developed by Rosen (1974). In effect, if a product class contains enough products with different combination of attributes, then it is possible to estimate an implicit price relationship that gives the price of any product as a function of its various characteristics. In order to express the hedonic price model analytically, let K represent a product class and Q_{jk} be a vector of characteristics, with j= characteristic and k=a specific good from that product class. Then, for that good k the hedonic price equation can be written as:

(1) $$P_k = F(Q_{1k}, Q_{2k}, \dots, Q_{nk})$$

For the present study, the product class (K) consists of herbicides used in agricultural production activities and k consist of herbicides used in corn and soybean production. In order to be able to formulate and estimate a hedonic pricing model five different groups of herbicide attributes were used: 1) production characteristics (efficacy against grasses and broadleaf weeds respectively and crop response[3]), 2) application period periods (pre-emergence, post-emergence, pre-plant and pre-emergence), 3) environmental statements (use with caution, ground water advisory, ground and surface water advisory, restricted), 4) herbicide selectivity (grasses, broadleaves, grasses and broadleaves), and, 5) mode of action groups (MOA) which is the biochemical or physical mechanism by which a herbicide kills plants (eight[4] MOA groups for soybean, and, seven[5] for corn). Definitions for those characteristics are provided on Table 1, definitions for mode of action groups are provided on Table 2.

The equilibrium relationship in equation (1), describes, how prices must relate to characteristics in order to eliminate incentives for consumers, or firms, to change their decisions. The marginal implicit price of a specific attribute can be obtained by differentiating the hedonic function with respect to that characteristic as noted in equation (2):

[3] Crop response illustrates the potential of a herbicide to injure a plant.
[4] (group 1, group 2, group 3, group 5, group 9, group 13, group 14 and group 15)
[5] (group 2, group3, group5, group 9, group 15, group19, group 27)

(2) $\frac{\partial p_k}{\partial Q_j} = P_{kj}(Q_1, Q_2, \ldots, Q_n)$

As far as the expected signs are concerned, following Beach and Carlson (1993), the a-priori hypothesis is to have positive signs for the production characteristics (i.e. efficacy levels) and negative for the hazardous ones (i.e. environmental statements and crop response). Regarding application periods, post-emergence products are expected to be cheaper, ceteris paribus, because they target specific weeds and are often not as broad spectrum in the number of weeds controlled, whereas many soil residual products provide broader spectrum of weed control.

Empirical Model

A central notion in the estimation of hedonic pricing models is the identification of the most appropriate functional form. The importance of this issue has been highlighted by many scholars in the literature (i.e. Cropper et al. 1988, Palmquist and Israngkura 1999, Ekeland et al. 2002, Rosen 1974 and Epple 1987). Due to the fact that economic literature places few restrictions on the form of the hedonic pricing models, several approaches have been used. Among the more commonly used methods is the Box-Cox transformation method (Box, Cox 1964). The present section describes how the Box-Cox transformation is used in order to select the most appropriate functional from, and how the empirical models were estimated. The most flexible form of the Box- Cox transformation is the following:

(3) $P_k^{\lambda} = \alpha_0 + \sum_{i=1}^{n} \alpha_i z_i^{\beta_i} + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} z_i^{\beta_i} z_j^{\beta_j}$

for all i,j where i and j index the characteristics and z, β are estimated from the data (Freeman III (2003)).

Since the primary objective of the present study is to describe the effects of different attributes on herbicide prices and estimate implicit prices for the characteristics of herbicides, a first step hedonic analysis was used (Rosen 1974) [6]. In order to select the most appropriate functional form the following Box-Cox transformation was applied to the dependent variable (herbicide price per application per acre):

$$(4) \quad P_h^{\lambda} = \begin{cases} \frac{P_h^{\lambda}-1}{\lambda}, & \text{When } \lambda \neq 0 \\ \ln(P_h), & \text{When } \lambda = 0 \end{cases}$$

For λ=1 this is a linear function. As λ approaches zero this becomes the semi-log form and finally for λ= -1 it is the reciprocal. The choice of this particular Box-Cox form was based on Cropper et al. (1988). Specifically, the authors illustrated that, when some of the variables in the hedonic model are measured as proxies, then the linear form outperformed the quadratic one.

The hypothesis of equal coefficients across years and across crops was tested with an F-test. Aggregation across years was not rejected, but aggregation across crops was rejected. Thus, results are presented separately across crops but aggregated across years. An additional specification issue considered was whether a hedonic pricing model for herbicides provides more accurate estimates by explicitly including as many groups of attributes as possible, avoiding co-linearity issues, or by including a cluster of characteristics in the form of mode of action groups. The second approach provides the advantage of implicitly incorporating herbicides chemical family based on their active ingredient. As a result of the aggregation and the specification issues the following two empirical models were estimated separately for corn and soybean herbicides.

[6] First step hedonic regression analysis means that product prices are regressed on characteristics. The second step approach uses the prices to identify willingness to pay for a given characteristic.

Model 1 (without mode of action):

$$(5) \quad P_h = \beta_0 + \beta_1(Production\ characteristics) + \beta_2(environmental\ statements) + \beta_3(Application\ period) + \beta_4(Herbicide\ selectivity) + \beta_5(Year) + \varepsilon$$

Model 2 (including mode of action):

$$(6) \quad P_h = \beta_0 + \beta_1(Production\ characteristics) + \beta_2(Environmental\ statements) + \beta_5(Year) + \beta_6(Mode\ of\ Action) + \varepsilon$$

Following Beach and Carlson (1993), herbicide price (P_h) is measured as the expenditure per application per acre rather than price per gallon. The reason for this measurement is that farmers are mainly interested for the price per application instead of the package price when selecting herbicides. Furthermore, herbicide efficacy level, measured in a ten point scale, is calculated as the average efficacy of each particular herbicide against grasses and broadleaf weeds. This calculation is based on efficacy ratings for each herbicide examined against selected grasses and broadleaf weeds, from the experiments of University of Kentucky extension service. The Box-Cox transformation returning the highest log-likelihood value is $\lambda=1$, corresponding to the linear form. Explanatory power, measured by adjusted R^2 was higher when efficacy values and crop response were linear. Multicollinearity problems occurred when site of uptake was included as a separate attribute in equation (5).

In order to explore the effect of MOA groups on price variation the second hedonic pricing model was estimated. The reason for dropping application period and plant selectivity from this model is that MOA groups affect how and when a herbicide is applied, thus, application period and herbicide selectivity are incorporated on the different MOA groups.

Explanatory Variables Selection and Data Description

The present section includes a description of the sources and the type of data used in the study. In order to be able to estimate a hedonic pricing model for herbicides, data on five different groups of attributes (production characteristics, environmental statements, Mode of Action (MOA) groups, application period, and plant selectivity) were collected. Moreover, data on the application rates were needed to calculate the dependent variable (price per application per acre). The selection of the herbicide attributes considered in the study is based on previous literature (Beach and Carlson 1993, Fernadez- Cornezo 2009, Lin et al. 1995), in conjunction with suggestions from University of Kentucky weed specialists[7].

Four main sources of data were used: (1) University of Kentucky Extension Service Publications, (2) USDA, (3) herbicide labels, and (4) Kentucky Farm Bureau. In detail, data for application period, herbicide selectivity, application rates, efficacy levels against broadleaf weeds and grasses for the examined herbicides were obtained from University of Kentucky Extension Service. An herbicide performance against a particular weed is considered poor if the rating is below five on the ten point scale and good if the rating is eight or higher. Information about environmental statements and Mode of Action groups were gathered from herbicide labels, USDA and University of Kentucky Extension Service publications. Herbicide prices, from 2000 to 2010 (excluding 2003 and 2006), were obtained from the Kentucky Farm Bureau. Data for those eight years gave a total of 171 observations for corn and soybean herbicides respectively. Complementary price data were collected through the Agribusiness Association of Kentucky,

[7] The authors would like to thank Dr. Jonathan Green, University of Kentucky weed specialist for his useful comments.

Southern States Coop., and herbicide retailers. Description of explanatory variables and summary statistics are provided on Table 1.

Fifty one herbicides are examined in the present study, 27 of which are for corn and 24 for soybeans respectively. Table 3 reports the common names and the active ingredients for those herbicides. The herbicides included in the study cover most of the herbicides used in Kentucky for corn and soybean production. The choice of these two particular crops was made for two main reasons. First, corn and soybeans are among the top agricultural commodities in Kentucky. Specifically, based on the value of receipts, corn was ranked 3rd in 2008 with 13.5% of total farm receipts ($ 653,037,000), behind horses and broilers and soybeans were ranked 5th with 7.9% of total receipts ($ 383,971,000) (USDA, ERS). Second, these crops were chosen because, more than 90% of the planted acres with those two crops are treated with herbicides (Table 4).

Environmental statements were used as an indicator of the herbicide toxicity levels, instead of a single LD_{50} value that was used in previous studies[8]. Environmental hazard statements provide the precautionary language advising of the potential hazards to the environment from the use, transport, storage or spill of the product. The information contained in these statements, generally, is based on the results of several acute toxicity tests including: (1) avian oral LD_{50}, (2) avian dietary LD_{50}, (3) freshwater fish LC_{50} and (4) acute LC_{50}. This approach enables us to better understand the effect of herbicides on the environment compared to the information provided from a single LD_{50} value.

[8] In toxicology the median Lethal Dose $LD_{50,}$ LC_{50} or LT_{50} of a toxic substance is the dose required to kill half the members of a tested population after a specified duration

Furthermore, compared to the previous literature, two additional herbicide characteristics, herbicides' Mode of Action and application period, were incorporated in the present study. The former, is the biochemical or physical mechanism by which an herbicide kills weeds. A plausible hypothesis is that MOA is a proxy for latent or not easily observed characteristics of herbicides such as the different types of injuries an herbicide may cause. Herbicides are often chosen for use based on their MOA. If one herbicide is ineffective against a specific type of weeds then, an herbicide with different MOA may provide better results. Moreover, when and how an herbicide is applied may be determined by its' MOA. The soybean herbicides examined in the present study, belong to eight different groups, whereas corn herbicides examined were included in seven different groups (Table 5). Most herbicides kill plants by disrupting or altering one or more of the plants metabolic processes or by disrupting the cellular membranes of the plant. Specific information about the MOA of herbicides examined in the present study is provided in Table 5. The inclusion of application period is based on Lin et al. (1995) who illustrated that application period is among the factors that influence herbicide use.

Empirical Results

The results obtained from the hedonic pricing model for herbicides, in conjunction with discussion about them are presented in this section. The empirical estimations of the two hedonic model specifications, one without mode of action groups and one with them, for each of the crops we are examining (corn and soybean) are reported in Tables 6 and 7.

In a general framework, the hedonic price coefficients illustrate the direct effect of the examined attributes on herbicide prices, that is, the marginal value of the attributes. For the binary variables (environmental statements, plant selectivity and application period) the hedonic price coefficients indicate the price difference over the base categories

Estimation for soybean herbicides

The results obtained from the first hedonic pricing model, specified in equation (5), indicate that production characteristics are significant determinants of soybean herbicide price (Table 6). Following the a-priori expectations, a positive sign was obtained for the efficacy levels and a negative one for the crop response. In detail, one point increase in the ten point scale efficacy level rating against grasses is associated with $1.89 increase in herbicide prices while, one unit increase in the efficacy scale for broadleaf weeds increases soybean herbicide prices by, approximately, $1.85. Thus, a transition from poor to good efficacy rating against grasses leads to a $7.56 increase in the herbicide price and a $7.4 increase in the case of broadleaf weeds. Additionally, one point increase in the four point scale rating of crop response is associated with a $5.5 decrease in soybean herbicide prices. As far as environmental statements are concerned, only the use with caution statement is statistically significant, with the expected negative sign, illustrating a $1.9 decrease in price compared to the base category of no environmental statement. These findings are consistent with Beach and Carlson (1993), who illustrated that weed control efficacy is an important determinant of soybean decisions, while, user safety was shown to be minor component in herbicide selection.

Furthermore, regarding the application period of soybean herbicides, from Table 6 it can be seen that the coefficients on pre-emergence and post-emerge herbicide are statistically significant and have a negative effect. This is expected because post-emergence herbicides target specific weeds and do not have as broad spectrum in the number of weeds controlled as the soil residual products. Finally, the price of soybean herbicides increases by $10.6, $22.4, and $16.4, if the herbicides are selective against grasses, broadleaf weeds, and grasses and broadleaf weeds, respectively compared to non selective herbicides (base category).

Overall, the high significance of the production characteristics and their large coefficients can act as a signal for soybean herbicide manufacturers to focus their research and development efforts on improving the production characteristics in order to increase the price. On the other hand, the fact that only one of the environmental statements was statistically significant and a minor component of herbicide price may indicate to policy makers that manufactures are not affected by those statements.

Estimation for corn herbicides

The findings of the first hedonic pricing model (equation (5)) estimation for corn herbicides, reported on Table 6, were not in agreement with our a-priory expectations. Specifically, from the production characteristics efficacy against grasses found to be significant price determinant with higher levels associated with higher prices as expected. However, efficacy against broadleaf weeds and crop response found to have a negative and positive impact on herbicide prices respectively. Additionally, all the environmental statements found to be significant determinants of herbicide prices but with a positive effect in prices. These results are in sharp contrast to our a-priori hypothesis. A possible explanation why these estimates fail to be in line with our initial hypotheses may be that some effects, related to the chemical family and the interaction of herbicides with the plant, not included in this model, have a highly significant impact on corn herbicide prices.

Herbicides hedonic pricing model including Mode of Action groups (MOA)

A second hedonic pricing model, specified by equation (6) was estimated with the intention to capture the effects of chemical interaction between herbicides and weeds on herbicide prices. This specification includes herbicides mode of action (MOA) in the vector of characteristics for the hedonic model. MOA is defined as the physical or chemical way by which a herbicide interacts with the plants. Furthermore, as mentioned earlier in the study, compared to the first estimation the application period and the herbicide selectivity are not implicitly included on the vector of characteristics because they are influenced by the MOA groups.

Estimation for corn herbicides including mode of action groups (MOA)

From Table 7 it can be seen that six out of seven mode of action groups for corn herbicides found to be significant determinants of their prices. In detail, group 15 (cell division inhibitors) is the mode of action group with the highest effect leading to a $15.6 increase in price of herbicides included in that group ceteris paribus. The MOA group with the second largest impact in price is group 19 (Auxin transport inhibitors) which is associated with a $9.3 increase in price for herbicides in that group. Only group 5 (photosynthesis inhibitors) found to have a negative effect on prices. ESP synthetase inhibitors (group 9), is the MOA group for corn herbicides that found not to be a significant price determinant.

Compared to the first model for corn herbicides, from the production characteristics, only efficacy against broadleaf weeds found to have an effect on price. However, in this approach the coefficient has the expected positive sign. In detail, a one point improvement in efficacy levels against broadleaf weeds is associated with a $0.44 increase in the corn herbicide price. Furthermore, as far as the environmental statements are concerned use with caution and ground and surface water advisory found to be significant price determinants. A use with caution statement (i.e. be careful when you use the herbicide in proximity to wells, or be careful when you mix it with other herbicides) leads to a $2.7 decrease in price while a ground and surface water advisory is associated with $2.2 price. Finally, an increase in the explanatory power is noticed as the adjusted R^2 increased from 0.67 (first model) to 0.83

Summarizing, inclusion of MOA groups not only highlighted the importance of the MOA groups as price determinants but also improved the model fit for corn herbicides providing results in line with the initial expectations and with the findings from Beach and Carlson (1993) paper.

Estimation for soybean herbicides including Mode of Action groups (MOA)

Similarly to corn herbicides the second hedonic pricing specification was estimated for the case of soybean herbicides. From Table 7 it can be seen that four out of eight MOA groups found to be significant price determinants for soybean herbicides compared to six out of seven for the case of corn. Furthermore, three out of those four had a negative impact on price in contrast to one out of six for the case of corn. Group 13 (pigment inhibitors) was the group with the highest positive effect on price with herbicides in that group having a $9.3 higher price. The highest negative impact found is from group 1(ACCase inhibitors) with herbicides included in that group have a $10.5 lower price compared to herbicides not in that group. The relatively high negative impact of MOA groups for soybean herbicide prices can be attributed to the dominance of characteristics that are associated with a price decrease. For example, herbicides that belong to group 1 (ACCase inhibitors) are mainly post-emergence herbicides. Based on the findings of the first model, the price of post-emergence herbicides is $5.7 lower compared to the base category of pre-plant herbicides. Similarly, the negative impact of EPSP synthetase inhibitors (Group 9) can be explained by the fact that herbicides in this group are generally non selective, and thus tend to have a lower price, which also is in line with the findings of our first model estimation.

Regarding the environmental statements use with caution and groundwater advisory found to be statistically significant in this model compared to only use with caution from the first model for soybean herbicides. Moreover, use with caution in this approach is associated with a $4.6 price decrease compared to a $1.9 price decrease from the first model.

As far as the time-dummy variables are concerned, their coefficients illustrate the estimated change in herbicide price over time. In Tables 6 and 7, it can be seen, that only for the years 2009 and 2010 there was a significant change in the price of soybean herbicides and for the years 2008 to 2010 for price of corn herbicides. The high values of adjusted R^2 in the two different hedonic pricing models estimated, specifically, 0.64 for the first model without the MOA and 0.66 for the full model with MOA for soybeans respectively, and 0.83 for the second model for corn illustrate that a high degree of herbicide price variability is explained by these models. Moreover, the high explanatory power is in agreement with the results of Beach and Carlson (1993), who found adjusted R^2 values equal to 0.53 for soybean and 0.75 to 0.85 for corn herbicides respectively.

Conclusions

This analysis used a hedonic price framework to identify characteristics with a significant impact on herbicide prices. Two distinct empirical models one with and one without including mode of action groups were estimated separately for herbicides used in corn and soybean production. The functional form of the empirical models was estimated with the use of Box-Cox transformation method.

The empirical results in line with our initial hypothesis and with previous literature (Beach and Carlson, 1993) indicate the importance of positive (efficacy against grasses and broadleaf weeds) and negative production characteristics (crop response). Moreover, most of the environmental coefficients were not statistically significant or, those that were (use with caution and groundwater advisory for soybean, use with caution and ground and surface advisory for corn) had a minor effect on prices. Since environmental statements are used as proxy for the toxicity of herbicides these results are in agreement with the findings of Beach and Carlson (1993) who found that toxicity does not have a sizeable impact on herbicide prices. Furthermore, explicit inclusion of the biochemical and physical way in which herbicides kill a weed, in the form of mode of action, not only improved the model fit for corn herbicides, but also illustrated with the high level of significance and the relatively large coefficients the importance of mode of action groups as price determinants. These findings can provide useful information for manufactures by guiding them regarding what characteristics their research and marketing efforts should be concentrating on. Moreover, a better understanding of mode of action may help policy makers introduce regulations to reduce the risk of herbicide usage without direct intervention in the markets.

A limitation of the present study is associated with the nature of first stage hedonic pricing analysis. Specifically, as mentioned by Rosen (1974) this type of analysis obtains short run equilibrium conditions revealing point estimates but not a general demand and supply schedule.

Finally, further research may use extensive on field surveys with farm managers in different states leading to a panel data hedonic pricing analysis that will determine consistency of results among different regions and will reveal information about the demand and supply.

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Table 1: Characteristics of Herbicides Used in the Study and Summary Statistics

		Soybean		Corn	
Variable	Meaning	Mean	Standard deviation	Mean	Standard deviation
Average application cost	Cost per application per acre	12.73	6.528	14.25	7.337
Production Characteristics[9]					
Efficacy against grasses	Average grass weed kill efficiency, based on a 10 point scale	5.266	2.979	5.582	1.902
Efficacy against broadleaf weeds	Average broadleaf weed kill efficiency, based on a 10 point scale	4.969	2.78	6.725	1.951
Crop response	Illustrates the potential of a herbicide to injure the crop based on a 4 point scale	1.2	0.919	1.7	1.358
Herbicide Selectivity					
Non selective	Herbicides that kill or injury any vegetation that is growing during treatment	0.0467	0.2117	0.035	0.184
Grasses	Herbicides that kill or injury mainly grasses	0.286	0.453	0.315	0.466
Broadleaves	Herbicides that kill or injury mainly broadleaf weeds	0.228	0.42	0.164	0.371
Grasses and broadleaved weeds	Herbicides that kill or injury both grasses and broadleaf weeds	0.438	0.497	0.485	0.501
Environmental Statements					
None	There is no environmental statement	0.228	0.42	0.129	0.336
Use with caution	Herbicides in this group should not be applied directly to water, or close to specific crops, or farmers should be careful when they mix them with other active ingredients	0.433	0.497	0.216	0.412
Groundwater advisory	There is the potential of contaminating the ground water	0.123	0.329	0.234	0.424
Ground and surface water advisory	There is a potential for contamination of ground and surface water.	0.216	0.412	0.105	0.308
Restricted use	Herbicides in this group have a higher potential for affecting the environment, the human health, or, animals	(-)	(-)	0.316	0.466
Application Period					
Pre plant	Herbicides in this group are used before the crop is planted	0.081	0.27	0.818	0.275
Pre emergence	Herbicides in this group are used before the weed emerge	0.175	0.381	0.129	0.335
Pre plant and pre emergence	Herbicide in this group can be used both before the crop is planted of before the weed emerges	0.204	0.404	0.427	0.496
Post emergence	Herbicides in this group are used after the weed has emerged	0.538	0.5	0.363	0.466

[9] For efficacy levels, the highest the value the better, for crop response the lower the value the better.

Table 2: Herbicide Classification by Mode of Action Groups

Group Code	Herbicide Classification	Site of Uptake	Plant Selectivity	Translocation	Symptomology
1	ACCase inhibitors (lipid synthesis) *Aryloxyphenoxy propionates *Cyclohexanediones	Foliage	Grasses	Phloem mobile	Growing point rots at the nodes, new leaves pull out easily
2	ALS inhibitors (amino acid synthesis) *Imidazolinones *Sulfonylureas *Sulfonamides	Soil or foliage	Selected broadleaves or grasses	Phloem mobile; xylem mobile in soil uptake	Chlorotic new growth. shortened internodes, reddened veins on soybeans, yellow flash in corn
3	Microtubule assembly inhibitors (root growth inhibitor) *Dinitroanalines	Soil	Grasses	Minimal transport	Stunting and clubbed root tips
5	Photosynthesis inhibitors *Triazines *Triazinones	Soil or foliage	Broadleaves	Xylem mobile (moves with water)	Contact burn of existing leaves, chlorosis of oldest leaf margins of seedligs ifsoil uptake
9	EPSP synthetase inhibitor (amino acid synthesis) *Glycines	Foliage	Generally non selective	Phloem mobile (with sugars)	Chlorotic new growth to death depending on rate, occasionally white flash
13	Carotenoid biosynthesis (pigment inhibitor)	Soil or foliage	Grasses and broadleaves	Xylem mobile	Bleaching of leaves
14	PPO inhibitors (cell membrane disruptors) *Diphenylethers *Triazolinones *N-phenylphthalamides *Pyrimidinedione	Soil or foliage	Broadleaves	Xylem mobile (moves with water), acts as a contact when applied postemergence	Contact burn of existing leaves, chlorosis of veins if soil uptake
15	Cell division inhibitors (seeding shoot growth inhibitors) *Chloroacetamides *Oxyacetamides	Soil	Grasses	Xylem mobile (minimal transport)	Leafing out underground wrapped leaves of grasses, bugging whipping
19	Auxin transport inhibitor	Foliage	Broadleaves	Phloem mobile	----
27	4-HPPDs (pigment inhibitors)	Soil or foliage	Broadleaves or grasses	Xylem mobile (moves with water)	Bleaching of existing leaves

Table 3: Common Names and Active Ingredients of Herbicides in the Study

Common Name	Active Ingredient	Common Name	Active Ingredient
Atrazine Nine-O	Atrazine	Authority Assist	Sulfetrazone +Imazethapyr
Balance Pro	Isoxaflutole	Authority MTZ	Sulfentrazone + Metribuzin
Beacon	Primisulfuron	Boundary	S-metolachlor + Metribuzin
Buccaneer Plus	Glyphosate	Canopy	Chlorimuron + metribuzin
Callisto	Mesotrione	Classic	Chlorimulon
Dual II Magnum	S-metolachlor	Cobra	Lactofen
Clarity	Dicamba	Command 3ME	Chlomazone
Guardsman Max	Dimethenamid-P+atrazine	Dual II Magnum	S-metolachlor
Harness Extra	Acetochlor + Atrazine	Extreme	Imazethapyr +Glyphosate
Impact	Topramezone	Flexstar GT	Fomesafen + Glyphosate
Keystone	Acetochlor + Atrazine	Fusilade DX	Fluazifop-P-butyl
Laudis	Tembotrione + Isoxadifen	Fusion	Fluazifop-P-butyl+ Flenoxaprp-ethyl
Lexar	S-metolachlor +Mesotrione +Atrazine	Gangster	Imazethapyr
Lighting	Imazethapyr +Imazapyr	Harmony Extra	Thifensulfuron +Tribenuron
Lumax	S-metolachlor +Mesotrione +Atrazine	Phoenix	Lactofen
Option	Foramsulfuron + Isoxadifen	Poast	Sethoxydim
Outlook	Dimethenamid- P	Poast Plus	Sethoxydim
Permit	Halosulfuron	Pursuit	Imazathepyr
Princep	Simazine		
Princep CAL 90	Simazine	Python	Flumetsulam
Prowl	Pendimethalin	Raptor	Imazamox
Resolve Q	Rimsulfuron + Thifensulfuron	Scepter	Imazaquin
Spirit	Prosulfuron +Primisulfuron	Spartan	Sulfentrazone
Status	Dicamba +diflufenzopyr	Valor SX	Flumioxazin
Steadfast	Nicosulfuron +Rimsulfuron		
Stout MP		Valor XLT	Flumioxazin + Chlorimuron
Volley AT	Acetochlor + Atrazine		

Table 4: Corn and Soybean Herbicide Usage in Kentucky

Corn				Soybeans			
Year	Acres Planted ('000s acres)	Acres treated with herbicides	Total quantity of herbicides used ('000s lbs)	Year	Acres Planted ('000s acres)	Acres treated with herbicides	Total quantity of herbicides used ('000s lbs)
1998	1,300	99 %	4,174	1998	1,220	98%	1,239
1999	1,320	94%	3,487	1999	1,200	94%	1,037
2001	1,200	97%	2,834	2000	1,200	88%	1,151
2003	1,170	97%	2,716	2006	1,380	97%	1,978
2005	1,250	100%	3,187				

Source: USDA-NASS

Table 5: Percentage of Herbicides in each Mode of Action Group

Soybean		Corn	
MOA Group	Percentage of Herbicides in the Group	MOA Group	Percentage of Herbicides in the Group
Group 1	20.47 %	Group 2	22.20%
Group 2	40.93%	Group 3	4.67%
Group 3	2.92%	Group 5	23.39%
Group 5	11.11%	Group 9	3.50%
Group 9	9.94%	Group 15	36.84%
Group 13	2.92%	Group 19	1.75%
Group 14	28.07%	Group 27	16.95%
Group 15	9.94%		

Note: The percentages do not sum up to 100% because the groups are not mutually exclusive

Table 6: Hedonic Model for Herbicide Prices Parameter Estimates

	Soybean		Corn	
	Coefficient	Standard error	Coefficient	Standard error
Production Characteristics				
Efficacy against grasses	1.890**	0.183	0.655**	0.296
Efficacy against broadleaf weeds	1.846**	0.512	-0.478*	0.278
Crop response	-5.520**	0.639	1.045**	0.344
Application Period				
Pre emergence	-6.209**	2.061	-0.743	2.660
Pre plant and pre emergence	-1.526	1.843	-10.648**	2.982
Post emergence	-5.725**	1.532	-2.031	2.099
Pre plant (Base Category)				
Plant Selectivity				
Grasses	10.611**	4.509	12.920**	3.143
Broadleaves	22.367**	3.188	10.348**	3.381
Grasses and broadleaved weeds	16.335**	2.969	7.061**	2.877
Non selective (Base Category)				
Environmental Statements				
Use with caution	-1.924*	1.113	3.193**	1.511
Groundwater advisory	1.538	2.025	9.206**	1.646
Ground and surface water advisory	1.100	1.119	7.111**	1.959
Restricted use	(-)	(-)	17.772**	1.848
None (Base Category)				
Year				
2000 (Base Category)				
2001	1.028	1.461	0.724	1.800
2002	0.485	1.464	0.023	1.712
2004	0.455	1.424	0.998	1.640
2005	0.222	1.410	2.473	1.624
2007	0.722	1.349	2.349	1.600
2008	0.947	1.331	4.106**	1.593
2009	2.681**	1.342	5.751**	1.547
2010	3.341**	1.345	4.621**	1.550
Constant	-11.04		-3.908	
Adjusted R^2	0.64		0.67	
Observations	171		171	

Note: *Significant at the 10% level; **Significant at the 5% level

Table 7: Hedonic Pricing Model for Corn Herbicides Parameters Estimate, With Groups Based on MOA

	Soybean		corn	
Variable	Coefficient	Standard error	Coefficient	Standard error
Mode of Action				
Group 1	-10.486**	5.618	NA	NA
Group 2	-5.410	1.758	6.207**	1.379
Group 3	-7.577**	4.575	5.567**	1.984
Group 5	2.364	1.764	-1.755**	0.885
Group 9	-2.984*	1.775	-0.244	2.073
Group 13	9.285*	3.228	NA	NA
Group 14	1.257	1.627	NA	NA
Group 15	-2.673	2.528	15.653*	1.654
Group 19	NA	NA	9.313**	2.243
Group 27	NA	NA	7.815**	1.014
Production characteristics				
Efficacy against grasses	0.944**	0.189	-0.247	0.235
Efficacy against broadleaved weeds	0.894	1.048	0.774**	0.251
Crop response	-2.999**	1.192	-0.112	0.266
Environmental statements				
Use with caution	-4.595**	1.075	-2.775**	1.185
Ground water advisory	-2.691*	1.425	-0.454	1.429
Ground and surface water advisory	0.977	1.328	-2.229**	1.773
Restricted	NA	NA	-2.08	2.097
None (Base category)				
2000 (Base category)				
2001	1.344	1.428	1.036	1.323
2002	0.435	1.429	-0.728	1.262
2004	0.575	1.393	0.160	1.209
2005	0.317	1.383	0.541	1.206
2007	0.780	1.319	0.821	1.184
2008	0.963	1.301	1.771	1.188
2009	2.743**	1.310	3.597	1.153
2010	3.355**	1.313	2.790	1.150
Constant	11.98		1.92	
Adjusted R^2	0.66		0.83	

Note: *Significant at the 10% level; **Significant at the 5% level