Journal of Agricultural and Resource Economics 43(2):151–171 ISSN 1068-5502

Factors Influencing Corn Fungicide Treatment Decisions

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Fungal disease management in U.S. corn production has undergone a major shift in the last 2 decades. The decision to apply fungicide, a management practice that was once rarely considered, is now contemplated annually by many U.S. corn producers. We investigate potential factors underlying the fungicide treatment decision. We use economics, agronomy, and plant pathology literature to develop a conceptual model of the fungicide treatment decision and test the model using a survey of Midwest corn producers. We find the treatment decision is positively related to perceived economic gains, but heuristic factors also have a strong influence.

Key words: maize, producer beliefs

Introduction

Fungal disease management in U.S. corn production has undergone a major shift in the last 2 decades. Traditionally, corn producers managed fungal disease through biological and mechanical controls such as natural predators, crop rotations, hybrid seed selection, and tillage practices (Mallowa et al., 2015; Wise and Mueller, 2011). In the mid-2000s, higher corn prices incentivized producers to shift to more continuous corn production and select hybrids based more on yield potential than disease resistance. These changes, coupled with less-intensive tillage practices and changes in weather patterns, have brought about more concerning fungal disease outbreaks (Wise and Mueller, 2011). Further, despite a lack of scientific consensus, some fungicide manufacturers started aggressive marketing campaigns suggesting fungicides provide yield benefits beyond controlling for fungal disease (Bradley, 2012; Mallowa et al., 2015; Wise and Mueller, 2011). The economics of fungal disease management changed, and many corn producers began to use fungicide (a chemical control) over traditional biological and mechanical controls.

From 1995 to 2014, U.S. corn fungicide applications increased from 17 thousand pounds to over 1.6 million pounds (NASS Chemical Use Survey).[1] The decision whether to apply fungicide, a management practice once rarely considered or implemented, is now contemplated annually by many U.S. corn producers. The rapid increase in fungicide treatments raises the question: What factors influence a corn producer's fungicide treatment decision and to what degree? Further, how do these factors align with those hypothesized in the economics, agronomy, and plant pathology literature?

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Partial funding for this research was provided by the Iowa EPSCoR. The authors gratefully acknowledge Clarke McGrath, Tyler Smith, Brian Rosburg, Jonathan McFadden, and Bryce Kanago for their helpful suggestions and the local corn farmers who beta-tested their survey. The authors also thank the editor, David Lambert, and the two anonymous referees for their helpful comments and suggestions. All remaining errors are their own.

Review coordinated by David K. Lambert.

[1] Details regarding the NASS Chemical Use Survey, including survey coverage, are available at http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.php.

Bradley (2012) provides some insight with a survey of 2009 Illinois Extension workshop attendees that included corn producers, company representatives, crop consultants, and others. Participants were asked to indicate which single factor, from a pre-specified list, was most important in their corn fungicide treatment decisions. Disease pressure and susceptibility of corn hybrids to disease comprised the highest percentage of responses. However, since respondents provided only the single most important factor, the survey was not able to provide insight into the relative importance of multiple factors or potential interrelationships among factors. More generally, there has been substantial work, primarily in plant pathology and agronomy, on the physiological effects of fungicide application (Mallowa et al., 2015; Paul et al., 2011; Paveley et al., 1997) and in economics on modeling optimal pesticide use (Antle, 1988; Carlson, 1970; Mumford and Norton, 1984; Sexton, Lei, and Zilberman, 2007). However, limited work has been done to examine producers' actual fungicide treatment decisions. Whether the factors hypothesized to influence fungicide treatment decisions explain actual treatment decisions remains an empirical question.

Limited empirical work on the corn fungicide treatment decision, we believe, is not due to a current lack of interest or importance but rather to the historically limited use of fungicide. Since more corn producers are considering fungicide as a way to manage fungal disease, it is an opportune time to examine which factors influence the treatment decision. Understanding the relative importance of these factors will improve the effectiveness of related policy efforts (e.g., disease resistance and water quality policies) and the communication efforts of agricultural advisors and extension agents. Further, the implications of our study are relevant not only for major corn-producing regions such as the U.S. Midwest, where corn fungicide applications are now common, but also for other regions like the European Union (EU), where the potential benefits of corn fungicide applications are being explored (Jørgensen, 2012).

Literature Review and Hypotheses Development

The use of chemicals in crop production has been a topic of interest across many fields. Given our focus on the corn fungicide treatment decision, we draw primarily from the economics, agronomy, and plant pathology literature on pesticide applications.[2,3] The economics literature provides a foundation for modeling the treatment decision, while the agronomy and plant pathology literature provides specifics pertaining to fungal disease and fungicide application. We use these strands of literature and crossovers between them to identify factors that potentially influence fungicide treatment decisions and to specify hypotheses that we can empirically test. Potential factors are categorized into four groups: i) economic factors, ii) risk factors, iii) heuristics, and iv) geographic- and producer-specific characteristics. In the following subsections, we discuss each factor group and how the related literature suggests these groups might directly or indirectly influence the fungicide treatment decision.

Economic Factors

We expect economic factors to play a large role in the fungicide treatment decision. If corn producers were profit maximizers with perfect information, standard economic principles would dictate fungicide treatment if the benefit of treatment exceeded the cost (Antle, 1988; Hillebrandt,

[2] Information was also gathered through correspondence with Iowa State University extension agronomists and from face-to-face interviews with Iowa corn producers.

[3] While commonly misused to refer only to insecticides, the term "pesticide" includes insecticides, herbicides, and fungicides (Wilson and Tisdell, 2001). The literature on fungicides is relatively limited, while the literature on other types of pesticides is more established. Therefore, we draw upon the similarities in terms of the decision-making process from literature on other types of pesticides.

1960; Mumford and Norton, 1984; Sexton, Lei, and Zilberman, 2007).[4] In reality, corn producers face considerable uncertainty at the time of the treatment decision. Nevertheless, corn producers might hold beliefs regarding the economic returns from treatment, and we expect that these beliefs play an important role in the treatment decision.

A common way to model fungicide benefits is as a damage-control input used to protect yield potential (Lichtenberg and Zilberman, 1986; Sexton, Lei, and Zilberman, 2007). Yield potential in our context is the producer's expected yield without fungal disease. In the standard damage-control model, fungicide does not increase yield potential but rather increases the *share* of potential yield achieved when fungal disease is present (i.e., reduces damage) (Sexton, Lei, and Zilberman, 2007). Therefore, if producers perceive fungicide treatment as a damage-control input, their perceived economic benefit from treatment is the market value of the yield potential protected.

Some fungicide manufacturers, however, have suggested that fungicide treatment provides a yield benefit beyond controlling for fungus through improved corn standability or harvestability, greater water and nitrogen use efficiency, and increased antioxidant activity (Munkvold et al., 2001; Paul et al., 2011; Wise and Mueller, 2011). We refer to this as a perceived "yield enhancement." While plant pathologists do not find consistent evidence of fungicide yield enhancement (Munkvold et al., 2001; Paul et al., 2011; Wise and Mueller, 2011), the perception of yield enhancement may influence corn producers' beliefs regarding yield benefits from fungicide treatment.

Based on our preliminary face-to-face interviews with corn farmers, we assume that corn producers hold beliefs regarding the distribution of "yield gains from treatment" (e.g., minimum, median, maximum). The phrase "yield gain from treatment" refers to the difference between expected yield with fungicide treatment and expected yield without fungicide treatment. We use this terminology to allow for flexibility in how corn producers develop their perceived yield benefits from treatment, whether through the damage-control approach (i.e., gains relative to no treatment) and/or a belief in a yield enhancement effect.[5] Similarly, we assume that corn producers hold beliefs regarding the corn price distribution. The distributions of the yield gain from treatment and the corn price, together with the cost of treatment, shape producers' beliefs regarding the economic gain from treatment. Therefore, our first hypothesis is

H_1: The producer's perceived economic gains from treatment are positively related to the treatment decision, *ceteris paribus*.

A vital aspect of H_1 is that the treatment decision depends on the producer's perceived economic gains from treatment rather than a theoretical or third-party value. Producers are likely to make pest-control decisions based on their perception of the disease problem, which may not necessarily reflect the actual situation (Mumford and Norton, 1984). Therefore, while H_1 hypothesizes a direct relationship between the producer's perceived economic gains and the treatment decision, an interesting side question is what factors indirectly influence the treatment decision through the producer's perceived economic gains. In particular, what factors influence the producer's perceived yield gains from treatment? If H_1 holds, then any factor that influences the producer's perceived yield gains will indirectly influence the treatment decision (see Figure 1).

Risk Factors

Corn producers face considerable uncertainty at the time of the fungicide treatment decision, and the degree of uncertainty regarding the economic gains from treatment as well as the producer's general risk attitude are likely to affect the treatment decision. Following Trujillo-Barrera, Pennings, and Hofenk (2016), we use the term "risk perception" to represent the producer's perception of the

[4] For inputs that have a quantity-based component or include successive treatments with diminishing returns, the optimal treatment decision is determined where the marginal benefit just exceeds the marginal cost (Hillebrandt, 1960; Mumford and Norton, 1984).

[5] Based on face-to-face interviews with Iowa corn farmers, the terminology "yield gain from treatment" is consistent with language commonly used among farmers.

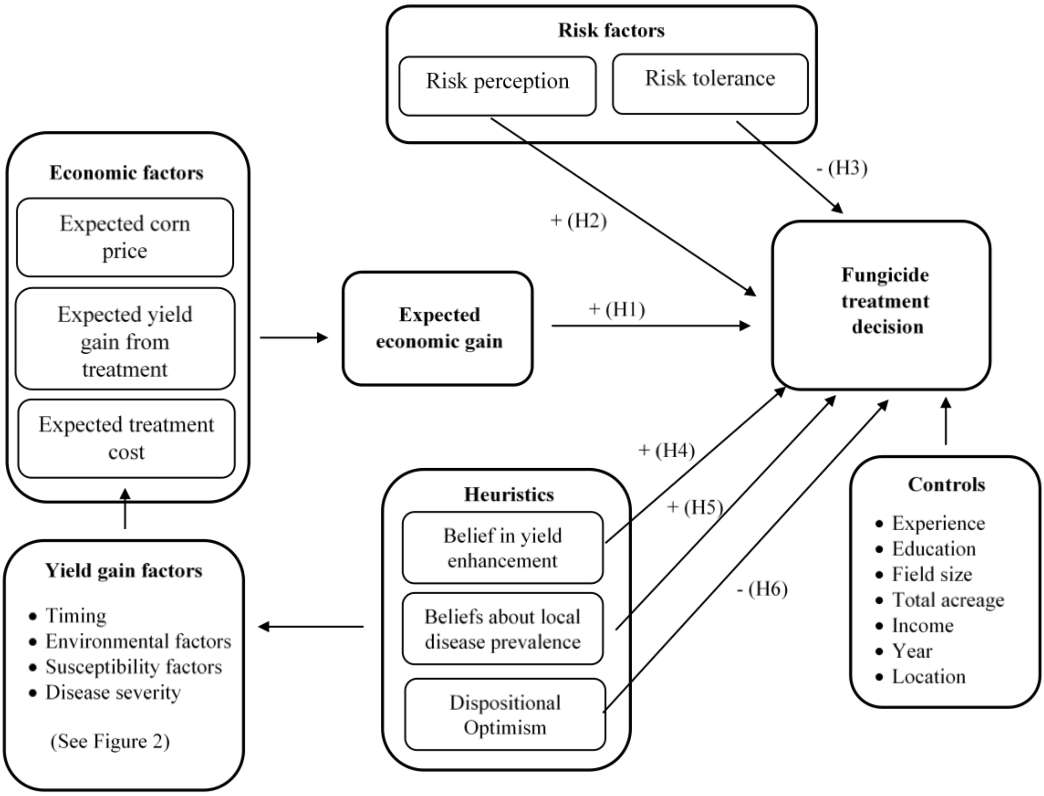

Figure 1. Conceptual Model of the Factors Influencing the Fungicide Treatment Decision

riskiness of the decision at hand and the term “risk tolerance” to represent the producer’s “general predisposition towards assuming financial risk” (Trujillo-Barrera, Pennings, and Hofenk, 2016, p. 364).

Pesticides are frequently modeled as a risk-reducing input (Sexton, Lei, and Zilberman, 2007),[6] and risk reduction has been identified as one of the main motivations for pesticide use (Reichelderfer, 1980; Wetzstein, 1981). The amount of expected risk reduction provided by fungicide treatment depends upon the degree to which the producer perceives fungicide treatment can reduce the magnitude (or range) of potential yield loss. The more risk reduction the producer expects to receive from treatment, the more likely the producer is to apply fungicide.[7] Therefore, defining risk perception based on the riskiness of fungal disease present (i.e., range in expected losses from not treating), our second hypothesis is

H_2: Fungal risk perception is positively related to fungicide treatment, *ceteris paribus*.

A large body of literature exists on the influence of general risk attitude on financial and other decisions (e.g., Caliendo, Fossen, and Kritikos, 2009; Dohmen et al., 2011; Menapace, Colson, and Raffaelli, 2016; Roe, 2015; van Winsen et al., 2016). All else equal, risk tolerance is generally

[6] While many models consider pesticides as a risk-reducing input, Horowitz and Lichtenberg (1994) provide a general model that allows pesticide to be a risk-reducing or risk-increasing input. They find that pesticide is a risk-reducing input if the main source of uncertainty is pest population, but pesticide may be a risk-increasing input if crop growth is random and pest population is high when crop growth conditions are good.

[7] A similar effect has been found in other inputs, such as nitrogen, where farmers apply above-optimal quantities for self-protection in the presence of uncertainty (Babcock, 1992).

believed to be positively related to the likelihood that a person chooses a riskier alternative.[8] In our context, not applying fungicide treatment is the riskier alternative when fungal disease is present. Therefore, we hypothesize that[9]

H_3: Risk tolerance is negatively related to fungicide treatment, *ceteris paribus*.

Heuristics

While we expect producers to carefully assess the expected costs and benefits from treatment and consider these factors in their treatment decision (H_1–H_3), actual pest management decisions are subjective and complex and therefore likely to be affected by heuristics (Mumford and Norton, 1984). Heuristics are cognitive shortcuts or rules of thumb that result from bounded rationality and are used by decision makers to solve complex problems (Kahneman, 2003).

A factor commonly discussed in the agronomy and plant pathology literature is the perceived yield enhancement effect proposed by some fungicide manufacturers. Plant pathologists conjecture that these perceived benefits may play a significant role in the fungicide treatment decision and lead some farmers to apply fungicide (Munkvold et al., 2001; Paul et al., 2011; Wise and Mueller, 2011); agronomists and plant pathologists sometimes refer to these treatments as "insurance applications" (Wise and Mueller, 2011). Belief in a yield enhancement effect may influence the producer's perceived yield gain from treatment and therefore influence the expected economic gain from treatment; we detail this potential indirect effect below. However, for producers who believe there to be little disease present or are highly uncertain about the degree of disease severity in their fields, belief in a yield enhancement effect may be used as a shortcut to help make the treatment decision (i.e., nudge them toward treatment). The belief in a yield enhancement effect may also represent or proxy the producer's general attitude about fungicide treatment. Therefore, we hypothesize that

H_4: Belief in a yield enhancement effect is positively related to fungicide treatment, *ceteris paribus*.

Another factor that might influence the producer's treatment decision both indirectly and directly is the extent to which the producer believes corn fungal disease to be present locally. If a producer believes there to be a high degree of fungal disease in the area, we expect the producer's expected yield gain from treatment and expected range in yield gain from treatment to be higher (this indirect relationship is detailed below). However, local disease pressure may also have a direct effect on the treatment decision. Producers who believe there to be little disease currently present or have uncertainty about the disease severity in their field may rely on a general rule of thumb, namely to apply fungicide if they believe local disease pressure to be high. If this is the case, shortcut decisions based on local disease pressure may also lead to "insurance applications." Therefore, we hypothesize that

H_5: The producer's perception regarding disease prevalence in the local area is positively related to fungicide treatment, *ceteris paribus*.

Corn producers' treatment decisions may also be influenced by their general optimism with regards to future outcomes. Dispositional optimism, defined as one's general expectation of good outcomes in one's life, has been found to influence a number of financial and other life choices (Armantier and Treich, 2009; Puri and Robinson, 2007; Manski, 2004; Scheier and Carver, 1987). If fungicide treatment serves as a form of self-insurance, we anticipate that a producer with higher dispositional optimism is less likely to apply fungicide. Therefore, we hypothesize that

H_6: Dispositional optimism is negatively related to fungicide treatment, *ceteris paribus*.

[8] The term "risk tolerance" is consistent with the language used by Trujillo-Barrera, Pennings, and Hofenk (2016) and is the inverse of risk aversion. Therefore, H_3 could alternatively be written as: "Risk aversion is positively related to fungicide treatment, *ceteris paribus*."

[9] Trujillo-Barrera, Pennings, and Hofenk (2016) suggest that risk perception and risk tolerance may have moderating effects on expected economic gains from treatment (H_1). We considered potential interaction/moderation effects but did not find evidence in support of moderating effects. Results for the moderating effects model are available upon request.

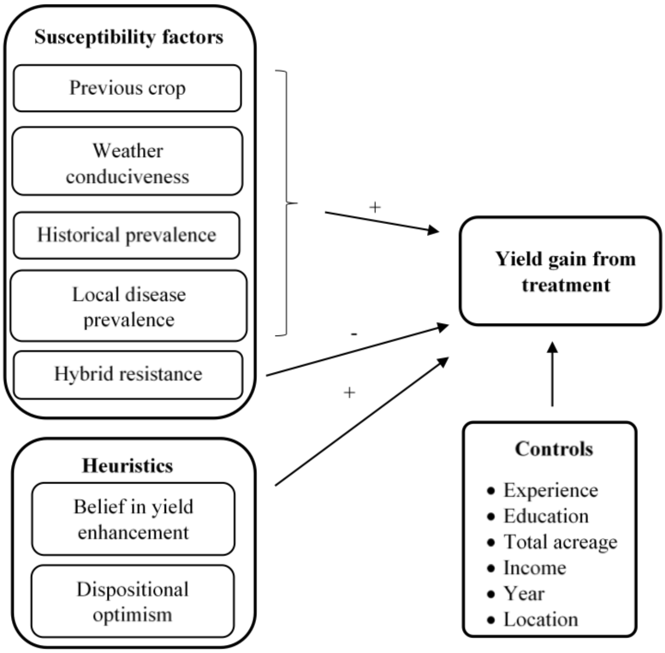

Figure 2. Conceptual Model of the Factors Influencing Producer's Beliefs about Yield Gain from Treatment

Geographic- and Producer-Specific Characteristics

Geographic- and producer-specific characteristics may also influence the fungicide treatment decision. We refer to these as "control"' variables in Figure 1. For geographic-specific variables, both location (e.g., region) and temporal conditions may affect the treatment decision. Controls for location capture potential differences in availability of professional farmer services and recommendations provided by local extension services (Khanna, 2001). To control for potential variation in the magnitude of the treatment decision across producers, we include field acreage. For producer-specific characteristics, we control for the producer's human capital accumulation (experience, education), farm-specific capital (total crop acreage), and financial characteristics (income). Previous literature does not provide sufficient evidence to establish *a priori* expectations about the influence of our control variables on the treatment decision (Knowler and Bradshaw, 2007; Trujillo-Barrera, Pennings, and Hofenk, 2016), and we therefore abstain from making formal hypotheses here.

Auxiliary Analysis: Yield Gain Factors

H_1 hypothesizes a direct relationship between the treatment decision and the producer's *perceived* economic gains from treatment. Since these gains are subjective, we propose a complementary question regarding what factors might indirectly influence the treatment decision through the perceived yield gain from treatment. Figure 2 overviews potential factors and their conceptual relationships to perceived yield gain.

If fungal disease is present, the degree to which fungicide treatment can preserve yield potential will depend on the developmental stage of the crop, environmental factors, susceptibility factors, and disease severity (Mallowa et al., 2015; Nelson and Meinhardt, 2011). More specifically, online decision guides recommend that corn producers take into consideration the previous crop planted, recent weather conditions, history of disease, and the hybrid resistance of the seed planted (Bradley et al., 2010; Pioneer, 2012; DuPont, 2013). We include these factors in the "Susceptibility" category in Figure 2. The practice of continuous corn production is considered to carry higher risk for fungal disease development (Wise and Mueller, 2011), and we therefore expect a producer's perceived yield gain from treatment to be higher in fields previously planted with corn. Similarly, we expect higher perceived yield gain if weather was conducive for fungal disease development, if there was historically a prevalence of disease in the field, and if the producer perceived a high degree of disease prevalence in the local area. Conversely, we expect yield gain from treatment to be negatively related to the hybrid resistance rating of the corn seed planted.[10]

In line with our conceptual model of the treatment decision, we include belief in the yield enhancement effect and dispositional optimism as potential heuristics that may influence perceived yield gain from treatment. We expect both of these factors to have a positive influence on the perceived yield gain from treatment. Finally, we include geographic- and producer-specific control variables.

Data and Methods

To empirically test our main hypotheses about the fungicide treatment decision, we employ logistic regression analysis. For our auxiliary analysis on the potential factors influencing perceived yield gains from treatment, we use standard ordinary least squares (OLS) regression. This section provides an overview of the survey design and corresponding data used to apply each empirical framework.

Survey Design and Variable Selection

A web-based survey was sent to Midwest corn producers in late July 2015 to assess their corn fungicide treatment decisions. Participants were recruited from a panel of farmers who had previously agreed to participate in online surveys in exchange for compensation.[11] The survey was sent via email to 2,318 panel members living in the top 10 corn-producing states.[12] To participate in the survey, a farmer had to have i) planted (nonorganic) corn during the 2015 growing season; ii) believed there to be fungal disease present in the 2015 corn acreage or believed there to be fungal disease present in their corn acreage for at least 1 year between 2010 and 2014 (even if they did not apply fungicide treatment); iii) been a primary decision maker regarding corn-production decisions; and iv) been 18 years or older.[13] A total of 250 surveys were completed; our response rate of 11% is similar to response rates from other farmer email or mail surveys (Kelsey and Franke, 2009; Krah et al., 2018; Menard et al., 2011; Pennings, Irwin, and Good, 2002).[14]

The portions of the survey relevant to this analysis involve i) a previous fungicide treatment decision on a field where the producer believed fungal disease to be present; ii) the expected fungicide treatment decision on a current field where the producer believes fungal disease to be present; iii) lottery scenarios; and iv) production and demographics. Below, we briefly describe the

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[10] Information on a hybrid's resistance rating, or—conversely—the hybrid's susceptibility to fungal disease, is readily available to farmers from seed companies (Bradley et al., 2010).

[11] The panel was initially recruited by Central Surveys, a market research company specializing in farm sector research; the panel is currently owned and managed by Strategic Market Research & Planning (SMR&P). All correspondence was managed by SMR&P.

[12] The top 10 corn-producing states were determined from 2014 USDA-NASS corn production data and include Iowa, Illinois, Nebraska, Minnesota, Indiana, South Dakota, Missouri, Ohio, Kansas, and Wisconsin. Approximately 86% of participants in the original (full) panel reside in these states.

[13] Participants were paid $20 by SMR&P for survey completion and guaranteed anonymity from the researchers. Participants also had the opportunity to win a large-sum lottery payment in addition to their fixed payment.

[14] While SMR&P could only provide limited information on the full panel due to confidentiality purposes, we did receive information on the distribution of total acres and age for the full panel. The distribution of our final dataset aligns with the distribution of the full panel for these variables.

questions included in each of these sections and how specific variables used in our analyses were constructed from the survey.[15]

Respondents were asked to indicate which years (if any) between 2010 and 2014 they believed fungal disease to have been present in their corn acreage (even if they did not apply fungicide treatment). For the most recent year indicated, respondents were asked follow-up questions regarding field size, field history, weather conditions, county-wide disease prevalence in corn acreage, hybrid resistance rating, corn yield expectations before the treatment decision, corn price expectations before the treatment decision, fungicide treatment cost, and their treatment decision. The treatment decision question required a "yes/no" response about whether the respondent applied fungicide, which is the relevant decision for farmers regarding fungicide treatment.[16] Follow-up questions, including the treatment decision, were not collected from producers who believed that there had been no fungal disease present in any of their corn fields between 2010 and 2014 (only 5% of respondents fit this criterion). Almost all producers (86%) indicated 2013 or 2014 as the most recent year in which they believed fungal disease to have been present.

Producers were then asked about the current (2015) growing season. A majority of producers (72%) believed fungal disease to be present in at least one field. These producers were asked follow-up questions similar to those above.

To test our hypotheses, we create a number of variables from the survey questions regarding previous and current treatment decisions. For H_1, we use producer responses regarding their corn price expectations ($/bu.), yield expectations (bu./acre), and treatment cost per acre. *Median corn price* is a value such that the producer expects the "price is 50% of the time above and 50% below this value." Similarly, *median corn yield gain* from treatment reflects a value such that the expected "yield gain is 50% of the time above and 50% below this value." *Treatment cost* is the total fungicide treatment cost per acre (spray and pass). These three variables effectively create three sub-hypotheses for H_1:

H_{1a}: Treatment is positively related to *median corn price*.

H_{1b}: Treatment is positively related to *median corn yield gain*.

H_{1c}: Treatment is negatively related to *treatment cost*.

We also use producer expectations regarding corn price and yield gains to capture fungal risk perception (H_2). *Corn price range* is the difference between the highest and lowest corn price the producer expected to receive for the field under consideration.[17] *Corn yield gain range* is constructed in a similar manner and is the difference between the highest and lowest expected corn yield gains from fungicide treatment in the field under consideration.[18] Based on these two variables, the two sub-hypotheses for H_2 are

H_{2a}: Treatment is positively related to *corn price range*.

H_{2b}: Treatment is positively related to *corn yield gain range*.

For local disease prevalence (H_5), we create two variables from the extent to which the producer believed corn fungal disease to have been present in the county-wide corn acreage (1: to a very small extent; 2: to a small extent; 3: to a moderate extent; 4: to a large extent; 5: to a very large extent). The two indicator variables are *county prevalence – moderate* (value of 1 if response = 3) and *county prevalence – large or very large* (value of 1 if response = 4 or 5),[19] yielding the following sub-hypotheses for H_5:

H_{5a}: Treatment is positively related to *county prevalence – moderate*.

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[15] Actual survey questions are available upon request.

[16] Unlike other inputs (such as nitrogen), where the relevant decision is quantity-based, the fungicide decision is typically whether or not to purchase a "standard" field application (i.e., preset or default quantity for the local area).

[17] High and low corn prices were reported in the same question set as *median corn price*.

[18] High and low corn yield gains were reported in the same question set as *median corn yield gain*.

[19] Excluded variable is *county prevalence – very small or small* (response = 1 or 2).

H_{5b}: Treatment is positively related to *county prevalence – large or very large*.

The third part of the survey posed a series of questions based on two lotteries. Lottery 1 was a fair coin flip with a payment of \$1,000 if the coin landed on heads and \$0 if on tails. Lottery 2 was a fair coin flip with a payment of \$10,000 if the coin landed on heads and \$0 if on tails. First, the producer was asked to report the probability (out of 100) they expected to win each lottery. Second, following the procedure outlined in Dohmen et al. (2011), the producer was asked to decide between fixed payment values (i.e., a guaranteed, no-risk option) and playing a lottery. For each lottery, the producer was shown a 15-row table with increasing fixed payment values. In each row, the producer was asked to make a decision between a fixed payment value and playing the specified lottery. For Lottery 1, the fixed payment values started at \$0 in row 1 and increased by \$50 increments up to \$700 in row 15. Lottery 2 had fixed payment values between \$0 and \$7,000 (\$500 increments). To ensure incentive compatibility, producers were informed that one respondent would be randomly selected among those taking part in the survey and paid according to their outcome (Dohmen et al., 2011).[20]

We use questions related to Lottery 2 to capture dispositional optimism (H_6) and risk tolerance (H_3). We chose to use responses to Lottery 2 over Lottery 1 because the scale of Lottery 2 (\$10,000) is more similar in magnitude to the economic decision of interest (i.e., fungicide treatment decision for a field); [21] therefore, Lottery 1 served as a practice round for respondents. The variable *optimism* is the producer's response to the following question about Lottery 2: "Considering your personal experience and luck, with what probability (out of 100) do you expect to win Lottery 2?" A 1-unit increase in *optimism* represents a 1-percentage-point increase in the probability the producer believes he will win Lottery 2.

To examine H_3, we use a measure of risk tolerance based on the producer's choices between playing Lottery 2 and accepting a fixed payment option (Dohmen et al., 2010, 2011; Hardeweg, Menkhoff, and Waibel, 2013). While not perfect, we believe the lottery-choice measure of risk preferences to be an acceptable proxy for risk tolerance.[22] The variable *risk tolerance* (assumed time invariant) reflects the fixed payment value (e.g., \$0, \$500, \$1,000, . . . , \$6,500, \$7,000) at which the producer switched from choosing "play Lottery 2" to "take the fixed payment" option. For ease of interpretation, we rescale the switch-point to a 0-to-7 scale. Therefore, a 1-unit increase in *risk tolerance* reflects a \$1,000 increase in the minimum fixed payment value at which the producer stops playing the lottery and accepts the fixed payment value instead.

The survey concluded with general production and standard demographic questions. Production questions focused on information the producer uses to make corn fungicide treatment decisions and potential heuristics related to the treatment decision. To evaluate the yield enhancement effect in H_4, we create an indicator variable *yield bump*, which takes a value of 1 if the producer indicated that the following statement describes his fungicide decision process: "I believe fungicide treatment provides a corn yield bump even when fungal disease is not present."

We also create a number of locational- and producer-specific control variables. *Field acres* measures acres in the specific corn field for which the producer answered fungicide treatment questions (year specific), while *total acres* is the farmer's total average annual crop acreage (including other crops); for ease of interpretation *total acres* is measured in thousands of acres. Similar to Khanna (2001), we measure human capital through two measures: years of farming experience (*experience*) (year specific) and an indicator variable (*college*) if the producer completed some college (community college or above). *Income* is a categorical variable based on 10 income

[20] After completing both tables, the computer identified an "active" lottery game for the respondent and an "active" row in that lottery table. For the selected respondent, their payment depended on their choice between the fixed payment value and lottery in the "active" row.

[21] Menapace, Colson, and Raffaelli (2016) show that behavioral validity is greater if the gamble task is of a similar scale to the economic decision of interest.

[22] Evidence suggests that, in spite of domain-specific variations (Pennings and Garcia, 2001), risk attitudes have a quantitatively important domain-general component (Einav et al., 2012).

brackets.[23] For locational controls, we construct the following regional/state variables: *Iowa* (excluded variable), *Illinois*, *Nebraska*, *Eastern states* (Ohio, Indiana), *Southern states* (Kansas, Missouri), and *Northern states* (Wisconsin, Minnesota, and South Dakota). As expected, a majority of responses are from Iowa and Illinois, the top two corn-producing states.

For the auxiliary analysis on perceived yield gains, we create variables regarding crop rotation, conduciveness of the weather to fungal disease development, historical fungal disease presence, and hybrid resistance. These variables all draw from the question set regarding previous and current treatment decisions. The (indicator) variable *corn following corn* takes a value of 1 if the field was in corn production the previous year. For weather conduciveness, producers were asked how conducive the weather had been for fungal development, followed by five answer options (1: not very conducive; 2: slightly conducive; 3: somewhat conducive; 4: conducive; 5: extremely conducive). We include three indicator variables based on the top three response options: *weather – somewhat conducive* (value of 1 if response = 3), *weather – conducive* (value of 1 if response = 4), and *weather – extremely conducive* (value of 1 if response = 5).[24] To measure historical fungal disease presence, producers were asked, "Historically, how often do you have corn fungal disease in this field (even if you do not treat)?" They were given four answer options (1: rarely; 2: some years; 3: most years; 4: every year). We include two indicator variables based on this question: *historical presence – some years* (value of 1 if response = 2) and *historical presence – most or every year* (value of 1 if response = 3 or 4).[25] Finally, producers were asked to classify the hybrid resistance rating of the seed planted, followed by five answer options (1: very poor; 2: poor; 3: average; 4: good; 5: very good). The variable *above average hybrid resistance* is an indicator variable of whether the producer reported either good or very good resistance (value of 1 if response = 4 or 5).

Data Summary

The observations included in our analysis are producer responses to a previous treatment decision (2013 or 2014) and the current (2015) treatment decision for those who believed fungal disease to be present in at least one field. Limiting our analysis to previous treatment decisions in 2013 and 2014 captures a majority of the previous treatment observations (86%) while mitigating potential recall issues. To the extent possible, variables are time-specific. However, some variables were only measured once (e.g., *optimism*, *risk tolerance*, *yield bump*), and we assume values did not change significantly between 2013 and 2015.

Since the objective of our analysis is to investigate factors that influence the corn fungicide treatment decision in a given year, we limit our analysis to producers that handle fungicide treatment as an annual decision (i.e., do not have a "default" treatment decision). Questions were included in the survey to help identify producers with default treatment decisions. First, we asked producers to indicate whether the following describes their fungicide decision process: "I always apply unless there is a major weather event" or "I never apply fungicide." We exclude respondents with a positive response to either question in our baseline specification; we assess the robustness of our results to including these respondents in sensitivity analysis. Second, we exclude responses where the producer indicated that the decision to not apply treatment was based on a crop insurance payout. Finally, we remove survey responses that were incomplete or inconsistent for the questions used in our model. The final dataset contains 228 responses.[26] Table 1 provides the descriptive statistics for the complete dataset and according to treatment decision.

[23] Income categories are as follows: 1 = <$50,000, 2 = $50,0001–$150,000, 3 = $150,001–$250,000, 4 = $250,001–$350,000, 5 = $350,001–$450,000, 6 = $450,001–$550,000, 7 = $550,001–$650,000, 8 = $650,001–$750,001, 9 = $750,000–$1,000,000, 10 = >$1,000,000.

[24] Excluded variable is *weather – not very or slightly conducive* (response = 1 or 2).

[25] Excluded variable is *historical prevalence – rarely* (response = 1).

[26] The 228 observations include 50 farmers with observations for only 1 survey year (either previous or current treatment decision) and 89 farmers with observations for both a previous and current treatment decision.

Table 1. Summary Statistics

	All ($N = 228$)				Treaters ($N = 131$)	Non-Treaters ($N = 97$)
	Mean	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Mean**
Treatment decision	0.57	0.5	0	1	1	0
Independent variables						
Median corn price ($/bu.)	4.2	0.7	3	7	4.2	4.1
Median yield gain (bu.)	9.1	4.5	0	30	10.3	7.4
Treatment cost ($/acre)	24.9	6.4	7	40	24.3	25.7
Corn price range ($/bu.)	1.2	0.8	0	5	1.3	1.1
Yield gain range (bu.)	15.2	8.0	0	50	16.9	12.8
Risk tolerance	2	2	0	6	2	2.3
Yield bump	0.15	0.36	0	1	0.21	0.07
County prevalence – moderate	0.48	0.50	0	1	0.46	0.51
County prevalence – large or very large	0.22	0.41	0	1	0.33	0.07
Optimism	48	12	0	90	48	48.3
Field acres	140	98	22	1,200	148	129
Experience	32.9	11.3	1	58	32.3	33.7
Total acres	1.50	1.23	0.1	10	1.69	1.23
2013 (excluded variable)	0.11	0.31	0	1	0.09	0.13
2014	0.43	0.50	0	1	0.43	0.42
2015	0.46	0.50	0	1	0.48	0.44
Income	3.0	1.8	1	10	3.1	2.9
College	0.75	0.44	0	1	0.78	0.70
Iowa (excluded variable)	0.46	0.50	0	1	0.50	0.39
Illinois	0.21	0.41	0	1	0.18	0.25
Nebraska	0.08	0.28	0	1	0.11	0.04
Eastern states (OH, IN)	0.09	0.28	0	1	0.10	0.07
Southern states (KS, MO)	0.06	0.24	0	1	0.05	0.08
Northern states (WI, MN, SD)	0.10	0.30	0	1	0.05	0.16
Additional variables for yield gain analysis						
Minimum yield gain	2.6	2.9	0	13	3.0	2.0
Maximum yield gain	17.8	8.7	0	50	20.0	14.8
Corn following corn	0.28	0.45	0	1	0.32	0.22
Weather – somewhat conducive	0.41	0.49	0	1	0.43	0.39
Weather – conducive	0.30	0.46	0	1	0.29	0.31
Weather – extremely conducive	0.20	0.40	0	1	0.25	0.12
Historical presence – some years	0.54	0.50	0	1	0.53	0.54
Historical presence – most or every year	0.29	0.46	0	1	0.33	0.25
Above average hybrid resistance	0.44	0.50	0	1	0.34	0.59
Other variables						
Male	0.99	0.11	0	1	0.98	0.99
Seeks advice of local agronomist most years	0.73	0.45	0	1	0.79	0.65
Scouts most years	0.79	0.41	0	1	0.83	0.74
Uses university provided information most years	0.27	0.45	0	1	0.28	0.26

Table 2. Logistic Regression Results for the Fungicide Treatment Decision ($N = 228$)

	Coefficient (β)	Std. Err. (SE β)	P>z (p)	Odds Ratio (e^{β})
Intercept	−5.19	2.90	0.07	0.01
Median corn price	0.73*	0.40	0.07	2.08
Median yield gain	0.24***	0.07	0.00	1.27
Treatment cost	−0.11***	0.04	0.00	0.89
Corn price range	0.53*	0.31	0.08	1.70
Yield gain range	0.07*	0.04	0.07	1.07
Risk tolerance	−0.22*	0.12	0.07	0.80
Yield bump	1.46**	0.66	0.03	4.32
County prevalence – moderate	0.98**	0.45	0.03	2.66
County prevalence – large or very large	2.81***	0.67	0.00	16.62
Optimism	−0.04**	0.02	0.01	0.96
Experience	−0.01	0.02	0.78	1.00
College	0.57	0.47	0.23	1.77
Field acres	0.00	0.00	0.94	1.00
Total acres	1.29***	0.32	0.00	3.64
Income	0.14	0.12	0.25	1.15
2014	1.63*	0.89	0.07	5.10
2015	1.54	0.98	0.12	4.64
Illinois	−1.48***	0.57	0.01	0.23
Nebraska	−0.10	0.82	0.91	0.91
Eastern states	−0.59	0.78	0.45	0.55
Southern states	−3.00***	1.00	0.00	0.05
Northern states	−3.54***	0.84	0.00	0.03

McFadden's pseudo-R^2 = 0.4065
Cragg–Uhler (Nagerkerke) R^2 = 0.572
Hosmer–Lemeshow χ^2 (8) = 2.47 with p = 0.9630
Correctly classified = 80.3%
LR χ^2 (22) = 126.43 with p = 0.0000

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.

Results

To assess the factors underlying the fungicide treatment decision and test our main hypotheses (H_1–H_6), we employ a logistic regression model in which the dependent variable is the producer's treatment decision (1 = treatment, 0 = no treatment). Examination of collinearity diagnostics did not identify significant concerns regarding multicollinearity among the independent variables; complete diagnostics and corresponding analysis are available in the Online Supplement.

Table 2 provides the logistic modeling results and a number of goodness-of-fit measures. The McFadden pseudo-R^2 and Cragg and Uhler's (Nagelkerke) R^2 indicate a relatively good fit of the model to the data, and there is no evidence of model misspecification based on the Hosmer–Lemeshow test. The model correctly classifies 80% of the treatment decisions.

The columns in Table 2 report the estimated coefficient values followed by the standard error and p value; the final column reports the odds ratio (e^{β}). Regression results provide support or partial support for all of our hypotheses. We use the 5% significance level as the minimum significance for hypothesis "support" and 10% as the minimum significance level for "partial support." These cutoffs are consistent with the general guidelines suggested by Weiss (2016), such that <5% reflects strong to very strong evidence while 5%–10% reflects moderate evidence.

Table 3. Summary of Empirical Results for the Hypotheses Regarding the Treatment Decision

Hypotheses		Expected Relationship	Finding
H_1	Expected economic gain	Positive	Support
H_{1a}	Median corn price	Positive	Partial support
H_{1b}	Median yield gain	Positive	Support
H_{1c}	Treatment cost	Negative	Support
H_2	Fungal risk perception	Positive	Partial support
H_{2a}	Corn price range	Positive	Partial support
H_{2b}	Yield gain range	Positive	Partial support
H_3	Risk tolerance	Negative	Partial support
H_4	Belief in yield enhancement (yield bump)	Positive	Support
H_5	Belief about local disease presence	Positive	Support
H_{5a}	County prevalence – moderate	Positive	Support
H_{5b}	County prevalence – large or very large	Positive	Support
H_6	Dispositional optimism (optimism)	Negative	Support

The likelihood of treatment increases with *median corn price* (H_{1a}) and *median corn yield gain* (H_{1b}) and decreases with *treatment cost* (H_{1c}), providing support for H_1. Therefore, as hypothesized, expected economic gain appears to underlie producers' treatment decisions. H_2, which hypothesizes a positive relationship between fungal risk perception and treatment, is partially supported by both H_{2a} (*corn price range*) and H_{2b} (*corn yield gain range*). Similarly, *risk tolerance* has the hypothesized sign (negative) and is statistically significant at the 10% level, resulting in partial support for H_3. We observe strong support for H_4. A belief in a yield enhancement effect (*yield bump*) increases the likelihood of treatment. Even after controlling for expected yield gains from treatment, a producer who believes in a yield enhancement effect is over four times more likely to apply fungicide than a producer who does not believe in a yield enhancement effect. Similarly, the county prevalence variables have strong, positive effects on the treatment decision, providing support for H_5. The results for H_4 and H_5 are suggestive of potential "insurance applications" (Wise and Mueller, 2011), which have important implications for profit margins, fungicide resistance issues, and water quality effects. Finally, holding all else constant, a producer with greater dispositional optimism (*optimism*) is less likely to apply fungicide treatment, providing support for H_6. Table 3 summarizes the six hypotheses, expected relationships, and findings.

Briefly looking at our control variables, we find that the likelihood of treatment increases with total crop acreage. This may reflect the magnitude of the fungicide treatment decision in question (i.e., a single field) relative to the producer's decision making portfolio (increasing with total acreage) or could be due to an economies of scale factor, where the farmer is spreading the fixed cost of fungicide application over more acres. Further, as expected, several temporal and geographic controls are significant.[27]

Auxiliary Results: Perceived Yield Gain

Our analysis of the treatment decision suggests that the producer's perceived *median corn yield gain* is a key factor underlying the treatment decision (positive and significant at the 1% level). Further, *corn yield gain range* (a measure of fungal risk perception) is also positively related to the treatment

[27] Including temporal and geographic interaction effects did not affect our main results (i.e., hypotheses support).

Table 4. OLS Regression Estimates for Perceived Yield Gain from Treatment

	Median Yield Gain		Yield Gain Range		Minimum Yield Gain		Maximum Yield Gain	
	β	SE β	β	SE β	β	SE β	β	SE β
Intercept	7.62	2.33	11.01	4.25	4.33	1.47	15.4	4.50
Corn following corn	0.33	0.70	−1.02	1.26	0.37	0.44	−0.65	1.35
Weather – somewhat conducive	1.09	1.12	−0.09	2.02	0.56	0.71	0.47	2.17
Weather – conducive	0.98	1.15	0.05	2.07	0.46	0.72	0.51	2.22
Weather – extremely conducive	3.95***	1.32	3.03	2.37	1.97**	0.83	5.00*	2.54
Historical presence – some years	−1.35	0.88	1.59	1.58	−2.22***	0.55	−0.62	1.70
Historical presence – most or every year	−2.16**	0.97	1.11	1.75	−1.90***	0.61	−0.79	1.88
County prevalence – moderate	−0.05	0.73	−0.62	1.31	0.23	0.46	−0.40	1.40
County prevalence – large or very large	0.93	0.99	3.39*	1.78	0.58	0.62	3.97**	1.91
Above average hybrid resistance	−0.67	0.62	−0.45	1.11	0.11	0.39	−0.33	1.20
Yield bump	0.34	0.85	−3.25**	1.53	1.41***	0.54	−1.84	1.64
Optimism	0.05**	0.03	0.09*	0.05	−0.01	0.02	0.07	0.05
Experience	0.03	0.03	0.04	0.05	0.00	0.02	0.03	0.05
College	0.88	0.73	0.92	1.31	−0.26	0.46	0.66	1.41
Total acres	−0.26	0.29	0.55	0.52	−0.43**	0.18	0.13	0.56
Income	−0.37**	0.18	−1.25***	0.32	0.10	0.11	−1.15***	0.34
2014	−1.50	1.03	−0.08	1.85	−0.06	0.65	−0.18	1.98
2015	−1.47	1.04	−0.66	1.88	−0.03	0.66	−0.77	2.02
Illinois	−1.01	0.83	−1.61	1.49	0.21	0.52	−1.40	1.60
Nebraska	0.58	1.16	1.20	2.09	−0.63	0.73	0.57	2.24
Eastern states	1.69	1.21	2.07	2.17	0.75	0.76	2.82	2.33
Southern states	−1.02	1.30	2.17	2.34	−1.51*	0.82	0.66	2.51
Northern states	−0.09	1.06	1.48	1.91	−0.15	0.67	1.34	2.05
R^2	0.19		0.17		0.22		0.18	

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level.

decision (significant at the 10% level). Here, we take a closer look at the factors underlying these perceived yield gains through OLS regressions. Table 4 provides results for four regressions with the following dependent variables: *median corn yield gain*, *corn yield gain range*, *minimum yield gain*, and *maximum yield gain*.

The factor with the most consistent effect across models is extreme weather conduciveness. If a producer believes weather to have been extremely conducive for fungal disease development, then all yield gain measures except *corn yield gain range* are higher; in particular, perceived *median corn yield gain* from treatment is about 4 bu./acre higher. Interestingly, the belief that weather has been extremely conducive for fungal disease development appears to have an asymmetric effect on expected yield gains. This belief corresponds to a 5 bu./acre increase in the maximum yield gain but only a 4 and 2 bu./acre increase in the median and minimum yield gain. However, the range in yield gain is not significantly affected.

Neither *corn following corn* nor *above average hybrid resistance* appears significant in explaining producers' perceived yield gains. As expected, if a producer believes there to be large or very large county-level disease prevalence, then *maximum yield gain* and *corn yield gain range* are higher. General optimism is also positively related to *median corn yield gain*. Historical presence has the opposite relationship (negative) to the one hypothesized (positive). *Historical presence – some years* is negatively related to the producer's *minimum yield gain* expectation, and *historical presence – most or every year* is negatively related to both the *median yield gain* and *minimum yield gain* expectations. This relationship may indicate that our historical presence measures are more reflective of producers' experiences with fungicide treatments in the field of interest (likely increasing with historical presence) rather than a measure of disease severity or susceptibility in the field. For example, consider a farmer who has had limited success with previous fungicide treatment in a field with substantial historical fungal disease presence; based on these experiences, the farmer may have lower yield gain expectations for this field compared to a field with less historical presence. These types of experiences may underlie the negative relationships observed in our results.

Interestingly, belief in a yield enhancement effect (*yield bump*) is positively related to *minimum yield gain* and negatively related to *corn yield gain range*; the former effect presumably drives the latter. *Yield bump* does not appear to influence *median* or *maximum yield gain* expectations. Given the producers in our dataset, we believe there is an intuitive explanation. Our analysis is limited to only those who believed there is some disease in the field; we do not observe yield gain expectations (or treatment decisions) among producers who believed no fungal disease to be present. Therefore, the observed yield gain perceptions are conditional on the belief that there is some level of fungal disease present. If a producer believes there to be at least some disease present, we expect the perceived median and maximum yield gains to depend primarily on factors related to the perceived severity of the disease present. The perceived minimum yield gain is a more complex story. Producers may be uncertain about the severity of disease and may place a nonzero probability that there is very little or no disease in the field. Given the possibility of limited disease presence, a belief in a yield enhancement effect may increase the perceived minimum yield gain from treatment (i.e., put a lower bound on yield gains) relative to someone who does not believe in a yield enhancement effect. In other words, for a producer who believes in a yield enhancement effect, the worst possible yield gain (i.e., minimum) may reflect the perceived yield enhancement value.

The R^2 values are fairly low across the four yield gain regression models (0.17–0.22), indicating a high degree of unexplained variability in the data. Therefore, in terms of the main analysis above, a major advantage of our survey design is that we were able to evaluate producers' fungicide treatment decisions using direct measures of producers' yield gains beliefs (e.g., *median corn yield gain* and *corn yield gain range*) rather than relying on a number of indirect and potentially incomplete measures.[28] In particular, the unexplained variability in the yield gain regressions may reflect unobserved information sources that producers use to form their yield gain expectations. While the information provided will differ by source and case, and therefore have differing effects on the perceived yield gains from treatment, we asked producers in our survey about three potential information sources. First, approximately 50% of our respondents said they base their fungicide treatment decisions primarily on the advice of their local agronomist or agricultural dealer.[29] This is in line with recent Iowa Farm and Rural Life Polls (IFRLP), in which 66% of Iowa farmers indicated they would go to an agricultural chemical dealer first for information on insect pest management (Arbuckle, 2014). Both our findings and those of the IFRLP show a significant increase from a 1994 survey conducted in central Illinois by Czapar, Curry, and Gray (1995) in which it was found that only 21% of respondents based their decisions primarily on advice from chemical dealers or consultants. This increased reliance emphasizes the need for well-trained local agronomists and agricultural dealers and demonstrates the importance of interactions between extension and local dealers such that producers receive consistent information.

Second, about 67% of our respondents indicated that they used university-provided information (e.g., extension websites, newsletters) in either some years or most years to help make fungicide treatment decisions.[30] This percentage is much higher than the 12% of Iowa farmers in the IFRLP that indicated they would go to Iowa State University extension as their *first* source of information regarding pest management decisions. Similarly, Czapar, Curry, and Gray (1995) found that only a small percentage of Illinois farmers indicated that they based pest management decisions directly on university recommendations. Therefore, while the IFRLP and Illinois survey indicate that most farmers may not use university-provided information as their primary (or first) source of information, we find that a majority of farmers are at least using university-provided information as supplemental information (e.g., in addition to information from agricultural chemical dealers). Supplementation with university-sponsored information is consistent with findings in the IFRLP regarding whom farmers *trust most* for information. When the IFRLP asked which source of information farmers "trust the most" for insect pest management (rather than which one they would go to first), the percentage rose for extension (22.5%) and declined for agricultural chemical dealers (56%). Therefore, the established link and relative trust between research/extension efforts and individual farmers present an opportunity for extension entities to influence or help guide producers' fungicide treatment decisions.

Third, 79% of our respondents scouted their acreage most years.[31] Sung and Miranowski (2016) note that informational technologies, such as field scouting, may reduce farmers' uncertainty regarding decisions; however, Czapar, Curry, and Gray (1995) note that the intensity of scouting varies widely across farmers (e.g., detailed field monitoring to cursory field visits), and it is therefore difficult to determine how scouting may influence the perceived yield gains and the final treatment decision.

Sensitivity Analysis

For robustness, we consider three alternative model specifications for the treatment decision analysis. In the baseline model specification, we excluded producers with a positive response

[28] In a re-estimation of the fungicide treatment decision adding all variables from the yield gain regressions (along with all variables from the baseline treatment model), *median corn yield gain* and *corn yield gain range* remained statistically significant. Therefore, our measures of producer beliefs regarding yield gains from treatment provide explanatory power regarding the treatment decision beyond that captured by the available indirect measures.

[29] Producers were asked whether the following describes their fungicide decision process: "I base my fungicide application decision primarily on the advice of my local agronomist or ag dealer."

[30] Producers were asked, "How often did you use university-provided information (e.g., extension websites, newsletters, etc.) to help make your fungicide application decisions?" They had four answer options: (1: never; 2: rarely; 3: some years; 4: most years).

[31] Producers were asked "Did you scout your corn acreage for fungal disease?" They had four answer options: (1: never; 2: rarely; 3: some years; 4: most years).

Table 5. Summary of Empirical Results for the Hypotheses Regarding the Treatment Decision for Alternative Specifications

	Hypotheses	Baseline	Include "Always" and "Never" Appliers	No Year Indicators	Probit
H_1	Expected economic gain	Support	Partial Support	Partial Support	Support
H_{1a}	Median corn price	Partial support	No support	No Support	Partial support
H_{1b}	Median yield gain	Support	Support	Support	Support
H_{1c}	Treatment cost	Support	Support	Support	Support
H_2	Fungal risk perception	Partial support	No support	Partial support	Support
H_{2a}	Corn price range	Partial support	No support	No Support	Support
H_{2b}	Yield gain range	Partial support	No support	Partial Support	Support
H_3	Risk tolerance	Partial support	Partial support	Partial support	Partial support
H_4	Belief in yield enhancement (yield bump)	Support	Support	Support	Support
H_5	Belief about local disease presence	Support	Support	Support	Support
H_{5a}	County prevalence – moderate	Support	Support	Support	Support
H_{5b}	County prevalence – large or very large	Support	Support	Support	Support
H_6	Dispositional optimism (optimism)	Support	Support	Support	Support

to either "I always apply unless there is a major weather event" ($N = 16$) or "I never apply fungicide" ($N = 16$). Our first alternative model specification evaluates the effects of including these producers. Second, while collinearity diagnostics did not identify significant concerns regarding multicollinearity (see Online Supplement), they did reveal moderate correlation between the year indicator variables and select control variables. Therefore, our second alternative model specification tests the sensitivity of our model results to the exclusion of the time indicator variables. Third, our baseline model specification relies on a logistic model specification. We chose a logistic model for our baseline model specification because of its mathematical convenience (Greene, 2008) and relative ease of interpretation (i.e., odds ratio); logistic models are also commonly used to analyze adoption decisions (Trujillo-Barrera, Pennings, and Hofenk, 2016; Knowler and Bradshaw, 2007). Our third alternative model specification considers a probit model.

Table 5 summarizes the six hypotheses and findings under the baseline and three alternative model specifications. Complete regression results for each model are available in the Online Supplement. With the inclusion of the "always" and "never" appliers, *median corn price* (H_{1a}), *corn price range* (H_{2a}), and *corn yield gain range* (H_{2b}) have the expected signs but are no longer statistically significant. While there is no longer support for H_{1a}, there is still strong support for H_{1b} and H_{1c}. The two sub-hypotheses for H_2 are no longer supported, indicating that the influence of fungicide as a risk-reducing input within producers' treatment decisions may be limited and sensitive to model specification. Conversely, the *yield bump* effect increases both in magnitude and statistical significance. With the "always" and "never" appliers included, a producer who believes in a yield enhancement effect is now over six times more likely to apply fungicide than a producer who does not believe in a yield enhancement effect (*ceteris paribus*).

The main results are generally robust to the exclusion of time indicator variables and probit specification. When time indicator variables are excluded, *median corn price* (H_{1a}) and *corn price range* (H_{2a}) are no longer statistically significant. However, the other sub-hypotheses for H_1 and H_2

remain supported such that we still observe partial or full support for all six hypotheses. Similarly, all six hypotheses remain supported with the probit specification, and H_2 increases from partial to full support.

Conclusions

With the rapid increase in corn fungicide applications over the past 2 decades, it is an opportune time to evaluate the factors influencing corn producers' fungicide treatment decisions. Understanding these factors has important implications for agricultural advisors and extension agents who communicate with farmers as well as the policy makers who wish to incentivize efficient fungicide use. We used a survey of U.S. Midwest corn producers to investigate the factors hypothesized in economics, agronomy, and plant pathology literature to be influential in the treatment decision. To our knowledge, this is the first study to empirically investigate factors influencing producers' actual fungicide treatment decisions.

As expected, a corn producer's perceived economic gain from treatment is positively related to fungicide treatment. We also find some evidence that treatment is positively related to the perceived risk regarding economic gains from treatment (but sensitive to the sample base) and negatively related to both risk tolerance and general optimism. However, our results also suggest that producers do not make actual fungicide treatment decisions from a pure damage-control perspective. Given the complexity of the decision and potential uncertainty about their beliefs in yield gains from treatment, producers tend to rely on other, heuristic-based factors. Even after controlling for perceived yield gains from treatment, a corn producer who believes in a yield enhancement effect is over four times more likely to apply fungicide than a producer who does not believe in a yield enhancement effect. This result suggests that belief in a yield enhancement effect may nudge some producers toward treatment. Similarly, we find that the probability of treatment is significantly affected by other, heuristic-based factors like dispositional optimism and beliefs regarding local disease prevalence.

The use of heuristic-based factors in the treatment decision is potentially indicative of "insurance applications," which are not only costly for producers but are also a social concern due to fungicide resistance and water quality implications (Hart and Pimental, 2002; Pimentel, 2005; Walker et al., 2009; Bradley and Pedersen, 2011; Wise and Mueller, 2011; Blandino et al., 2012; Mallowa et al., 2015). Producers in our survey indicated a strong reliance on university-related (extension) materials, local agronomists, and agricultural dealers. Therefore, outreach by these entities regarding the yield enhancement effect and/or the costs associated with "insurance applications" may be a viable option.

Given the survey design, our analysis is limited to the treatment decisions of those who believed at least some disease to be present. Therefore, we do not observe treatment decisions for those who did not believe any disease to be present. Some producers who believe in a yield enhancement effect may apply fungicide even if they do not believe any disease to be present. If this is the case, then our findings regarding the role of the yield enhancement belief on the treatment decision may be an underestimate, suggesting an interesting avenue for future research.

While our empirical analysis considered U.S. Midwest corn producers, our general findings have important implications for other major corn-producing regions. For example, while fungicide use is widely used in EU wheat production (Gianessi and WIlliams, 2011), corn fungicide applications are currently limited, and EU researchers are accessing the potential benefits of fungicide to mitigate corn leaf disease (Jørgensen, 2012). Our findings suggest that as research develops and researchers provide recommendations to EU corn producers, researchers should consider the potential for producers to use heuristic-based factors in addition to economic factors to make their treatment decisions. Understanding these potential heuristic-based factors will be important if actual pest management strategies are to align with European directives for sustainable pesticide use (Jørgensen, 2012; Meissle et al., 2010).

[Received October 2017; final revision received April 2018.]

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Online Supplement

To address potential multicollinearity concerns, Supplement Table S1 provides collinearity diagnostics for the fungicide treatment decision analysis. None of the independent variables have a variance inflation factor (VIF) greater than 10 or tolerance value less than 0.10, which would indicate serious collinearity problems. However, the year indicator variables (*2015* and *2014*) have VIFs around 5, which may raise some concern. Further evaluation of those variables revealed year 2015 is negatively correlated with *median corn price* (−0.40) and *county prevalence – moderate* (−0.19) and positively correlated with *county prevalence – large or very large* (0.27). Year *2014* is negatively correlated to *county prevalence – large or very large* (−0.18) and positively correlated with *county prevalence – moderate* (0.15). For this reason, one of our sensitivity specifications considers the exclusion of the time indicator variables. Supplement Table S2 provides the logistic regression results for this alternative model specification. Also included in Supplement Table S2 are regression results when "always" and "never" appliers are included and results from a probit specification (see the section on sensitivity results for details and discussion).

Table S1. Collinearity Diagnostics

	VIF	Tolerance	R^2
Median corn price	2.12	0.47	0.53
Median yield gain	1.78	0.56	0.44
Treatment cost	1.37	0.73	0.27
Corn price range	1.29	0.77	0.23
Yield gain range	1.98	0.51	0.49
Risk tolerance	1.20	0.83	0.17
Yield bump	1.23	0.81	0.19
County prevalence – moderate	1.53	0.66	0.34
County prevalence – large or very large	1.71	0.59	0.41
Optimism	1.29	0.78	0.22
Experience	1.29	0.78	0.22
College	1.23	0.81	0.19
Field acres	1.23	0.81	0.19
Total acres	1.73	0.58	0.42
Income	1.52	0.66	0.34
2014	4.95	0.20	0.80
2015	6.08	0.16	0.84
Illinois	1.33	0.75	0.25
Nebraska	1.28	0.78	0.22
Eastern states	1.46	0.68	0.32
Southern states	1.29	0.78	0.22
Northern states	1.36	0.73	0.27
Mean VIF	1.83		

Table S2. Alternative Specifications for Fungicide Treatment Decision

	Include "Always" and "Never" Appliers		No Year Indicators		Probit	
Variables	**Coeff. (β)**	**Std. Err. (SE β)**	**Coeff. (β)**	**Std. Err. (SE β)**	**Coeff. (β)**	**Std. Err. (SE β)**
Intercept	−3.42	2.51	−2.05	2.03	−3.08	1.61
Median corn price	0.54	0.38	0.29	0.28	0.43*	0.22
Median yield gain	0.22***	0.06	0.22***	0.06	0.13***	0.04
Treatment cost	−0.11***	0.03	−0.10***	0.03	−0.07***	0.02
Corn price range	0.43	0.29	0.45	0.30	0.33**	0.16
Yield gain range	0.05	0.03	0.07*	0.04	0.04**	0.02
Risk tolerance	−0.17	0.12	−0.20*	0.12	−0.14*	0.07
Yield bump	1.91***	0.61	1.53**	0.65	0.81**	0.35
County prevalence – moderate	0.82*	0.42	0.96**	0.44	0.55**	0.25
County prevalence – large or very large	2.61***	0.61	2.79***	0.65	1.69***	0.33
Optimism	−0.04**	0.02	−0.04**	0.02	−0.02**	0.01
Experience	0.00	0.02	−0.01	0.02	0.00	0.01
College	0.36	0.45	0.58	0.47	0.31	0.29
Field acres	0.00	0.00	0.00	0.00	0.00	0.00
Total acres	1.40***	0.31	1.35***	0.32	0.76***	0.16
Income	0.09	0.11	0.12	0.12	0.08	0.06
2014	0.98	0.80	–	–	0.91*	0.53
2015	0.78	0.89	–	–	0.86	0.58
Illinois	−1.47***	0.55	−1.46***	0.55	−0.85***	0.32
Nebraska	−0.16	0.81	−0.06	0.80	0.01	0.41
Eastern states	−0.44	0.69	−0.36	0.75	−0.33	0.39
Southern states	−2.97***	0.98	−2.87***	0.99	−1.75***	0.49
Northern states	−3.92***	0.80	−3.45***	0.81	−2.06***	0.43
R^2	0.4175		0.3950		0.4087	

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level. Probit model estimated using robust standard errors.