U.S. Soybean Producer Perceptions and Management of Soybean Rust in the United States under the USDA Pest Information Platform for Extension and Education

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Recent survey data are examined to improve current understanding of the factors that help to determine the value of information reported on a website that serves as the centerpiece of the USDA's "Soybean Rust Integrated Pest Management—Pest Information Platform for Extension and Education." Respondents' initial beliefs about their chances of experiencing a rust outbreak are shown to affect the likelihood that soybean producers will visit the website and change their management of fungicide use as a result.

Key Words: Asian soybean rust, probability beliefs, PIPE website, ARMS data, USDA Rural Development Broadband Program

Asian soybean rust is a plant disease caused by an airborne, fungal pathogen, *Phakopsora pachyrhizi*. Yield losses, due to reduced numbers of pods, beans per pod and bean weights, and fungicide cost increases, have been attributed to rust outbreaks everywhere soybeans are grown; however, *P. pachyrhizi* was only very recently reported in the Americas. Rust was first reported in Brazil and Paraguay in 2001, where it became widespread in areas where soybeans are produced, because climatic conditions and the availability of suitable hosts promote proliferation of the fungus year-round. It was first reported in the United States in November 2004 (USDA 2006). Although the pathogen can overwinter in southeastern coastal areas on uncultivated plants, such as kudzu, it cannot survive the winter where the majority of soybeans are produced (Pivonia and Yang 2004). As a result, rust outbreaks have not been as widespread in the United States as in South America. Analysis of climatic data, however, suggests that it is possible for rust to occur everywhere U.S. soybeans are produced. Based on assumptions regarding regional impacts on yields and fungicide application costs associated with a fully established population of *P. pachyrhizi*, simulation results indicate that between 14 and 55 percent of planted acres might receive fungicides at an annual cost between $262 and $1,736 million (2006 US$), and that aggregate returns to soybean production might decline between 3 and 21 percent (Livingston et al. 2004, Johansson et al. 2006).

P. pachyrhizi can survive the winter in northern Mexico, the northern Caribbean islands, and along the coastlines of Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and Texas. However, over 96 percent of U.S. soybeans are produced in other states (USDA 2008). The likelihood and severity of a rust outbreak occurring on a specific farm in areas where the majority of soybeans are produced is therefore very difficult to gauge at the beginning of any growing season, because it depends on the status of the pathogen

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in the south, the distance between the farm and southern source areas, how those areas expand northward during the growing season, the number of spores blown onto the farm when soybeans are present, contemporaneous weather conditions, and whether and how fungicides are applied.[1] Fungicides must be used between developmental stages R1 (beginning-bloom) and R6 (full-seed) to reduce yield loss efficiently in the event that spores arrive on the farm when conditions suit development of an outbreak. Preventative fungicides, which reduce the likelihood of an outbreak, must be applied shortly before spores arrive, and curative fungicides, which reduce the effects of an outbreak, must be applied shortly after arrival.

Because resistant plant varieties are not available, soybean producers must choose between three management options, which are to apply no fungicide whether or not rust occurs, to monitor their fields and apply a curative fungicide if an outbreak is observed, or to apply a preventative fungicide before spores arrive (Dorrance, Draper, and Hershman 2007). To improve the ability of producers to determine whether, when, and what type of a fungicide application might be needed, the U.S. Department of Agriculture (USDA) facilitated the development of the "Soybean Rust Integrated Pest Management—Pest Information Platform for Extension and Education" (PIPE), which is a coordinated surveillance, reporting, forecasting, and research program with land-grant universities, state departments of agriculture, and industry (U.S. Government Accountability Office 2005). Sentinel soybean plots and kudzu stands are monitored for evidence of rust in southern areas, where the pathogen overwinters, and in major production areas. The presence of rust, which is confirmed by diagnostic testing and scouting, is reported daily at the county level on a publicly available website, on which plant pathologists at land-grant universities also describe management alternatives.

Roberts et al. (2006, 2009) examined the determinants and characteristics of the value of the information reported on the PIPE website. In their analysis, the value of the information is the difference between the expected value of returns to the optimal management option chosen after and before the information is received, both of which depend on a representative soybean producer's subjective belief about the probability of experiencing a rust outbreak. For the Corn Belt, they found that it is optimal to apply no fungicide at probability beliefs between zero and 0.18, to monitor and apply a curative fungicide if rust is observed at probability beliefs between 0.19 and 0.62, and to apply a preventative fungicide at probability beliefs greater than 0.62. In addition, they found that information reported on the PIPE website is more valuable for soybean producers whose probability beliefs are near levels separating the optimal choice sets, because it is more likely to affect management behavior by changing those beliefs.

More generally, their analysis suggests that the value of the information is highest at initial probability beliefs in the interior of the unit interval, covering a range bounded roughly by the probability beliefs separating the optimal choice sets. This set of beliefs includes the critical levels, which separate the optimal choice sets, at which the value of information is highest, and beliefs in between the critical levels, which are also characteristic of a high degree of ambiguity relative to more certain beliefs that rust will or will not occur. The objectives of the current analysis are to examine recent survey data to improve understanding of the factors that determine probability beliefs, the relationship between PIPE website visitation and probability beliefs, the use of fungicides to control rust, and whether information found on the website is more likely to modify the management behavior of producers who are ambiguous about their chances of experiencing a rust outbreak relative to producers who have more certain expectations.

The only estimates of the potential economic impacts of soybean rust are based on assumptions and simulation results (Livingston et al. 2004, Johansson et al. 2006). For comparison purposes and to provide background for the subsequent analysis, survey data and county-level yield data (USDA 2009), which became available after these studies were conducted, are used to estimate fungicide costs and to assess the geographic extent and severity of rust outbreaks during 2005–2008. In the following section, to improve understanding of the determinants of probability be-

[1] *P. pachyrhizi* cannot survive without a suitable host and, if the weather is too dry, hot, or cold, an outbreak is less likely to occur and, if one does, less likely to be severe, even when a host is present upon landfall.

liefs, an ordered-probit model is used to examine relationships between probability beliefs, farm location, and other farm and producer characteristics. In particular, the estimates are used to test whether soybean producers in more southern locations, where rust outbreaks have occurred frequently, believe a rust outbreak is more likely to occur than producers in more northern locations, where rust outbreaks have occurred much less frequently.

In the next section, a probit model is used to improve understanding of the factors that might help explain PIPE website visitation. The value of the information reported on the PIPE website might depend on producers' probability beliefs; however, it also clearly depends on whether the information is received, either directly or indirectly. A probit model is used to test whether and how website visitation depends on producers' probability beliefs, as well as variables that characterize financial well-being, because soybean producers with less debt who earn more might be more able to purchase computers and afford the monthly fees charged by Internet-service providers than producers with more debt who earn less. The analysis conducted in this section might have implications for the USDA Rural Development Broadband Program to make Internet access more readily available in rural areas.

In the next section, a probit model is used to improve understanding of the factors that might help explain the likelihood of fungicide use, including measures of financial well-being, because fungicides are expensive; the purchase of federal crop insurance, which requires producers to apply fungicides if so advised by "agricultural experts"; and reliance on other external sources of information, concerns about which have been raised regarding undue influence of fungicide manufacturers. In the following section a bivariate, probit model, accounting for sample-selection bias, and other statistical methods are used to examine empirical support for the theory that the information reported on the PIPE website is more likely to alter the management behavior of soybean producers who are more ambiguous about their chances of experiencing a rust outbreak than producers who are initially more certain about their chances (Roberts et al. 2006, 2009). The article closes with a summary of the empirical results and policy implications.

Fungicide Costs and the Geographic Extent of Rust Outbreaks During 2005–2008

In this section, the responses of U.S. soybean producers who filled out 3,042 usable, field-level questionnaires in USDA's 2006 Agricultural Resource Management Survey (ARMS) are examined to estimate the aggregate cost of rust management.[2] Yield (USDA 2009) and rust-confirmation (PIPE website) data for 2005–2008 are also used to examine the geographic extent and severity of rust epidemics during this period. According to the survey data, 2.242 (±0.533) million soybean acres were treated with fungicides to manage rust in 2006, at a total cost of $76.875 (±$18.109) million, which is below the previous lower-bound projection of $262 million (Livingston et al. 2004). The previous lower bound is for a low-spread scenario, in which rust outbreaks and fungicide applications are assumed to occur on 9.84 million soybean acres planted in Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Tennessee, Virginia, and West Virginia, which is 60 percent of the projected number of acres planted to soybeans in those states. Rust was actually confirmed in more states in 2006 (Alabama, Arkansas, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, Texas, and Virginia); however, fungicides were applied to only 5 percent of the acres planted to soybeans in those states.

According to the survey data and the PIPE website, rust was confirmed in sentinel soybean plots and kudzu stands in counties with 7.431 (±1.001) million planted soybean acres. Over 1.017 (±0.166) million acres in those counties received fungicides, and almost 1.225 (±0.154) million acres received fungicides in counties in which rust was not confirmed in 2006. According to USDA (2009)

[2] Visit the Economic Research Service's ARMS Briefing Room at http://www.ers.usda.gov/Briefing/ARMS/ for more information about ARMS and to examine the 2006 questionnaire. In the current section only, descriptive statistics using these data are weighted to account for the non-random nature of the sample, and a delete-a-group, jackknife estimator is used to compute standard errors (Dubman 2000); 95 percent confidence levels follow the ± symbol. This is not done in the remainder of the article for simplicity, and because smaller subsets of the data are examined in subsequent sections, where it is inappropriate to use the weights to make inferences about the U.S. population. In subsequent sections, therefore, statistical inference is with respect to the survey respondents.

and the PIPE website, an average 6.106 (±3.492) million acres were planted to soybeans in counties in which rust was confirmed during 2005–2008. Using the 2006 estimates as a guide suggests that an average annual \$63.168 (±\$36.125) million has been spent applying fungicides to 1.842 (±1.054) million soybean acres during this period.[3] Additionally, the data on soybean yields in counties with and without rust suggest that the yield impacts of rust have been mild relative to previous projections (Table 1). Mean yields are generally not statistically different and more likely as not to be higher for counties with rust than for counties without rust.

Recent data therefore suggest that previous projections (Livingston et al. 2004, Johansson et al. 2006) might have overestimated annual fungicide costs and economic impacts. However, it is important to note that the number of counties with positive rust confirmations has increased steadily since 2005. Rust was confirmed in 147, 287, 355, 392, and 576 counties in 2005, 2006, 2007, 2008, and 2009, respectively. This suggests that *P. pachyrhizi* populations are still in the process of evolving toward a steady-state, equilibrium level in southern areas. The previous projections are based on assumptions associated with an established population, which has apparently yet to be realized; therefore, the estimates reported here might not be directly comparable.

Determinants of Probability Beliefs

In this section, the responses of U.S. soybean producers who filled out 1,884 usable, field- and farm-level questionnaires in 2006 are used to examine the relationship between the probability belief, farm location (latitude and longitude), producer characteristics (age and educational attainment), measures of financial well-being (dummy variables indicating whether gross sales exceed \$500,000, whether the debt-to-asset ratio exceeds 0.4, and whether the spouse's primary occupation is off-farm), and whether the producer rotated the field to different crops. The impact of farm location, particularly the latitude of the farm, is included in the model to test whether soybean producers in more southern locations believed a rust outbreak was more likely to occur than producers in more northern locations, where rust has occurred less frequently. Empirical support for this hypothesis, an assumption maintained by Roberts et al. (2006, 2009) to estimate information values, provides empirical support for their assumption and indicates that the survey respondents were knowledgeable about rust in 2006.

Age and educational attainment and measures of financial well-being are included in the model to examine their effects on probability beliefs. One of the reasons producers rotate the fields they plant to soybeans and corn is to reduce the cost of managing pests; however, rotating will not reduce the likelihood that a rust outbreak will occur. A dummy variable, equal to one for respondents who planted corn on the majority of the surveyed field in the spring of 2005, is included to test whether the respondents who rotated believed a rust outbreak was less likely.

Soybean producers were asked to choose among the following the response that best described their belief, held at the beginning of the growing season, regarding the probability that a rust outbreak would occur in 2006: very likely (=0), somewhat likely (=1), uncertain (=2), somewhat unlikely (=3), or very unlikely (=4). To account for the ordering inherent in the dependent variable, an ordered probit model, which is based on a latent regression, $y_i^* = \mathbf{x}_i^{\prime}\beta + \varepsilon_i$, was estimated; where $\mathbf{x}_i$ is a nine-by-one vector of explanatory variables, $^{\prime}$ is the transpose operator, β is a nine-by-one vector of coefficients, and ε_i is a standard-normal disturbance (Greene 1993). Producer *i*'s actual probability belief, y_i^*, is not observed; what is observed is producer *i*'s response to the question in the survey:

$$
\begin{aligned}
(1) \qquad y_i &= 0 \text{ if } y_i^* \le 0 \\
&= 1 \text{ if } 0 < y_i^* \le \mu_1 \\
&= 2 \text{ if } \mu_1 < y_i^* \le \mu_2 \\
&= 3 \text{ if } \mu_2 < y_i^* \le \mu_3 \\
&= 4 \text{ if } \mu_3 < y_i^*,
\end{aligned}
$$

where μ_1, μ_2, and μ_3 are scalars estimated with β.

[3] In this calculation, 6.106 (±3.492) million acres is multiplied by 0.302 = 2.242/7.431, the number of acres receiving fungicides divided by the number of acres in counties with rust confirmations in 2006. The estimate of acres receiving fungicides is then multiplied by \$34.29 = \$76.875/2.242, which is the 2006 estimate of fungicide material and application costs per treated acre.

Table 1. Mean Soybean Yields by State in Counties in Which Rust Was and Was Not Confirmed to Be Present

	2005		2006		2007		2008	
State	No Rust	Rust	No Rust	Rust	No Rust	Rust	No Rust	Rust
Alabama	31.6	37.3**	19.0	27.2	18.8	26.6**	36.0	33.2[a]
Arkansas	32.3		29.8	34.1**	27.3	35.5***	37.5	35.5
Florida	35.0	31.5[a]	24.9	27.0[a]		24.3		37.8[a]
Georgia	25.3	29.4*	23.9	30.0*	30.5	31.2	25.4	31.2*
Illinois	45.0		47.6	42.1***	41.8	44.8	46.2	44.8
Indiana	48.8		49.3	47.2	43.8	40.1[a]	43.6	
Iowa	52.1		49.8		51.6	51.5	44.7	
Kansas	37.3		34.0		35.4	32.8	36.6	
Kentucky	40.3		44.8	43.5	28.5	24.3	30.9	33.5**
Louisiana	31.7		31.5	35.5**	38.3	40.9	31.4	32.5
Maryland	33.2		33.5		27.4		31.8	35.5[a]
Mississippi	34.5		22.0	29.8*	31.9	43.8***	33.0	39.0[a]
Missouri	35.4		35.5		35.7	37.8	37.3	
Nebraska	50.5		50.7		51.2	49.1	47.5	
North Carolina	27.0	27.6	34.2	31.4**	19.1	22.4	32.8	31.3
Oklahoma	28.1		20.7		27.7	24.9	26.5	
South Carolina	21.0	19.9	29.9	28.9	16.7	25.0**	30.0	27.6
Tennessee	37.8		36.4	37.4	18.4	19.8	32.1	34.0
Texas	30.1		27.2	27.0	37.5	36.9	21.3	
Virginia	31.5		30.1	30.9	27.7	29.8	31.2	31.4

[a] There are not enough observations in each sample to compute the *t* statistic.

Notes: Yields are in bushels per harvested acre (USDA 2009) in counties in which rust was and was not confirmed (PIPE website). Means are statistically different at the 0.01***, 0.05**, and 0.1* levels. Population variances were not assumed equal, and the Satterthwaite degrees-of-freedom approximation was used (Casella and Berger 1990, pp. 396–397).

Maximum-likelihood estimates, asymptotic standard errors, marginal effects, and sample means of the independent variables included in the model are reported in Table 2. For a dummy variable, the marginal effect is the change in the estimated probability that the dependent variable is either zero, one, two, three, or four, when the dummy variable is one and zero, with the remaining variables evaluated at their means. For a continuous variable, and the intercept, the marginal effect is the derivative of the estimated probability with respect to the variable, with all of the other independent variables evaluated at their means. Standard errors for the marginal effects were computed using the delta method (Greene 2008).[4]

Of the 1,884 soybean producers who responded to the separate field- and farm-level questionnaires, 2.5 percent believed a rust outbreak was very likely, 6.5 percent believed a rust outbreak was somewhat likely, 18.3 percent were uncertain about the likelihood they would experience a rust

[4] The marginal effects and the standard errors of the marginal effects reported throughout this article were computed using code written in Matlab, which is available from the author upon request.

Table 2. Maximum Likelihood Estimates for Ordered Probit Model of Producers' Beliefs about the Likelihood of a Rust Outbreak

Dependent variable	0 = very likely, 1 = somewhat likely, 2 = uncertain, 3 = somewhat unlikely, 4 = very unlikely
Observations	1,884
Iterations	18
Log likelihood, unrestricted (L_u)	-2,337.17
Log likelihood, restricted (L_r)	-2,381.91
-2(L_r–L_u)	89.47 ***

			Marginal Effects					
Variable	Coefficient	Std. error	Very likely	Somewhat likely	Uncertain	Somewhat unlikely	Very unlikely	Mean
intercept	-1.6365 ***	0.4479	0.2623 ***	0.1638 ***	0.2013 ***	-0.0177	-0.6097 ***	
= 1 if operator had some college	-0.0381	0.0503	0.0061	0.0038	0.0047	-0.0004	-0.0142	0.54
= 1 if debt-to-asset ratio ≥ 0.4	0.0545	0.0509	-0.0088	-0.0055	-0.0067	0.0007	0.0203	0.62
= 1 if gross value of sales ≥ $500,000	0.0168	0.0521	-0.0027	-0.0017	-0.0021	0.0002	0.0063	0.37
= 1 if spouse's occupation off-farm	-0.0126	0.0506	0.0020	0.0013	0.0016	-0.0001	-0.0047	0.46
= 1 if operator planted corn last	-0.0153	0.0546	0.0024	0.0015	0.0019	-0.0002	-0.0057	0.64
age of operator	0.0025	0.0022	-0.0004	-0.0003	-0.0003	0.0000	0.0009	53.47
latitude of surveyed field	0.0538 ***	0.0073	-0.0086 ***	-0.0054 ***	-0.0066 ***	0.0006	0.0200 ***	39.93
longitude of surveyed field	-0.0077	0.0048	0.0012	0.0008	0.0010	-0.0001	-0.0029	-90.31
μ_1	0.4267 ***	0.0273						
μ_2	1.0685 ***	0.0283						
μ_3	1.7205 ***	0.0341						

Notes: Data are from the 2006 field- and farm-level ARMS questionnaires of soybean producers. Estimates are significant at the 0.01***, 0.05**, and 0.1* levels. The likelihood ratio test statistic is chi squared, with eight degrees of freedom, under the null hypothesis that all slope coefficients are zero. For a dummy variable, the marginal effect is the change in the estimated probability that the dependent variable is zero, one, two, three, or four, when the dummy variable is one and zero, with the remaining variables evaluated at their means. For a continuous variable, or the intercept, the marginal effect is the derivative of the estimated probability with respect to the variable, with all variables evaluated at their means. Standard errors for marginal effects (not shown because of space limitations) were computed using the delta method (Greene 2008). See equation (1) for the definitions of μ_1, μ_2, and μ_3.

outbreak, 22.8 percent believed a rust outbreak was somewhat unlikely, and 49.9 percent believed a rust outbreak was very unlikely. The latitude of the surveyed soybean field is the only statistically significant determinant of the respondents' probability beliefs (Table 2). The marginal effects of latitude, all but one of which are statistically significant at the 1 percent level, indicate that respondents were less likely to believe a rust outbreak was very likely, somewhat likely, or uncertain, and more likely to believe a rust outbreak was very unlikely as the latitude increased. These estimates, and the statistically insignificant estimate on the rotation dummy, indicate that the respondents were knowledgeable about the geographic distribution and other characteristics of soybean rust.

PIPE Website Visitation

Only 16.8 percent of the 1,884 respondents who filled out usable, field- and farm-level questionnaires reported visiting the PIPE website during the 2006 growing season. In this section, a probit model is used to examine the relationship between website visitation, probability beliefs, producer characteristics (age and educational attainment), and measures of financial well-being (dummy variables indicating whether gross sales exceed $500,000, whether the debt-to-asset ratio exceeds 0.4, and whether the spouse's primary occupation is off-farm). It is reasonable to posit that soybean producers who believe a rust outbreak is more likely are also more likely to visit the website, *ceteris paribus*. This hypothesis is tested by including separate dummy variables indicating whether the producer believed a rust outbreak was very likely, somewhat likely, uncertain, or somewhat unlikely.

The age and educational attainment of the respondent are included to examine whether these characteristics help explain the likelihood of website visitation. It is, for example, reasonable to posit that producers with college experience might be more likely to visit the website than producers without college experience, because producers in the former group might be more familiar with using computers to access the Internet than producers in the latter group. Measures of financial well-being are included, because it is reasonable to posit that producers with less debt and more income are more able to afford a computer and the monthly fees charged by Internet-service providers and, as a result, more likely to visit the website, *ceteris paribus*, than producers with more debt and less income.

The results indicate that respondents who believed a rust outbreak was very likely, somewhat likely, uncertain, or somewhat unlikely visited the website more frequently than respondents who believed a rust outbreak was very unlikely (Table 3). The coefficient estimates and marginal effects are all positive and statistically different from zero, the intercept is negative and statistically significant, and the point estimates of the probability of visiting the website are 0.24, 0.28, 0.19, 0.17, and 0.12 for respondents who believed a rust outbreak was very likely, somewhat likely, uncertain, somewhat unlikely, and very unlikely, respectively. Respondents with some college experience and respondents who earned more revenue were more likely to visit the website than respondents without college experience and respondents who earned less revenue; and those with higher debt-to-asset ratios were less likely to visit the website than those with lower debt-to-asset ratios. The results reported in Table 3 suggest that soybean producers who believe an outbreak of rust is more likely are more likely to visit the PIPE website than producers who believe an outbreak is less likely, and that the USDA Rural Development Broadband Program might help such producers.

Fungicide Use

Only 5.7 percent of the 1,884 respondents who filled out usable, field- and farm-level questionnaires reported at least one fungicide application during the 2006 growing season. In this section, a probit model is used to examine factors that help explain the likelihood of fungicide use, including producer characteristics (age and educational attainment), measures of financial well-being (dummy variables indicating whether gross sales exceed $500,000, and whether the debt-to-asset ratio exceeds 0.4), whether the producer purchased federal crop insurance, the latitude of the surveyed field, whether the farm is located in a county in which rust was confirmed in 2006, and dummy variables indicating the primary sources of external information used by the producer to inform pest-management decisions.

The age and educational attainment of the respondent are included in the probit model to test whether these characteristics help explain the likelihood of fungicide use. Measures of financial well-being are included because fungicides are expensive, and it is therefore reasonable to posit that producers with less debt and more revenue are more able to afford and, as a result, more likely to use fungicides, *ceteris paribus*, than producers with more debt and less revenue. Federal crop insurance covers losses associated with soybean rust; however, to receive compensation for related yield losses, producers are required to follow "good farming practices," which means at least one fungicide application if advised by an "agricultural expert" to control rust. It is therefore reasonable to posit that soybean producers who participated in the federal crop insurance program in 2006 were more likely to use fungicides than producers who did not. A dummy variable indicating whether the respondent purchased federal

Table 3. Maximum Likelihood Estimates for Probit Model of Website Visitation

Dependent variable	= 1 if farmer visited the PIPE website
Observations	1,884
Iterations	32
Log likelihood, unrestricted (L_u)	-806.41
Log likelihood, restricted (L_r)	-853.67
-2(L_r–L_u)	94.51 ***

Variable	Coefficient	Std. error	Marginal effect	Std. error	Mean
intercept	-1.2545 ***	0.2172	-0.2987 ***	0.0508	
age of operator	-0.0036	0.0034	-0.0009	0.0008	53.47
= 1 if operator had some college	0.3478 ***	0.0742	0.0816 ***	0.0170	0.54
= 1 if debt-to-asset ratio ≥ 0.4	-0.1517 **	0.0740	-0.0368 **	0.0182	0.62
= 1 if gross value of sales ≥ $500,000	0.3988 ***	0.0725	0.1000 ***	0.0189	0.37
= 1 if spouse's primary occupation was off-farm	0.0965	0.0736	0.0231	0.0176	0.46
= 1 if operator believed rust outbreak very likely	0.4385 **	0.2070	0.1120 *	0.0624	0.02
= 1 if operator believed rust outbreak somewhat likely	0.5757 ***	0.1328	0.1561 ***	0.0423	0.06
= 1 if operator uncertain about likelihood of rust outbreak	0.2752 ***	0.0956	0.0649 ***	0.0239	0.18
= 1 if operator believed rust outbreak somewhat unlikely	0.2113 **	0.0891	0.0482 **	0.0211	0.23

Notes: Data are from the 2006 field- and farm-level ARMS questionnaires of soybean producers. Estimates are significant at the 0.01***, 0.05**, and 0.1* levels. The likelihood ratio test statistic is chi squared, with nine degrees of freedom, under the null hypothesis that all slope coefficients are zero. For a dummy variable, the marginal effect is the change in the estimated probability that the dependent variable is one, when the dummy variable is one and zero, with the remaining variables evaluated at their means. The marginal effect of a probability-belief dummy is computed similarly; however, because these are mutually exclusive dummy variables, the other probability-belief dummies are set to zero, as opposed to their samples means. For a continuous variable, or the intercept, the marginal effect is the derivative of the estimated probability that the dependent variable is one with respect to the variable, with all variables evaluated at their means. The standard errors for the marginal effects were computed using the delta method (Greene 2008).

crop insurance is therefore included in the probit model.

Because the majority of rust confirmations in 2006 occurred in the southern United States, it is also reasonable to posit that soybean producers in northern areas were less likely to apply a fungicide than producers in southern areas. The latitude of the surveyed field is included in the model to test this hypothesis. Accounting for latitude, it is also reasonable to suppose that soybean producers in counties with rust confirmations were more likely to use fungicides than producers in counties in which rust was not confirmed. A dummy variable indicating whether the surveyed field is in a county in which rust was confirmed in 2006 is included to test this hypothesis. Finally, although the mechanism by which this might occur is not clear, concerns have been raised that manufacturers of fungicides might unduly influence their use. This hypothesis is tested by including dummy variables indicating primary sources of external information (other than the PIPE website) that the producer used to inform pest-management decisions, including a dummy variable indicating whether the information was from a farm-supply or chemical dealer.

The impact of website visitation on fungicide use, accounting for soybean producers' probability beliefs, is examined in the next section using the responses to a question added to the survey with this specific purpose in mind.[5] Dummy variables indicating the initial probability beliefs of respondents are also not included, because the determining factor is the probability belief held directly prior to fungicide use. Moreover, the latitude of the surveyed field, which is correlated with the initial probability belief (Table 2), is included.

The likelihood of fungicide use declined, but only very slightly, with the age of the primary operator, perhaps because it was not economical to use fungicides before rust was introduced into the United States, and that, as a result, soybean producers who were older were slightly less inclined to apply fungicides than less experienced producers (Table 4). Having some college experience had a positive but statistically insignificant effect on the likelihood of fungicide use. Fungicide use was more likely on farms with greater than or equal to $500,000 in annual sales, perhaps because operators of larger farms were more able to afford fungicides than operators of smaller farms. However, the probability of fungicide use increased by only 0.04 on these very large operations. Having a debt-to-asset ratio greater than or equal to 0.4 had a negative but statistically insignificant impact on the likelihood of fungicide use. These results suggest that soybean producers were not constrained financially in their use of fungicides to manage rust in 2006.

Soybean producers who purchased federal crop insurance were slightly more likely to use fungicides than producers who did not, likely because the receipt of an indemnity in the event of a rust outbreak requires producers to follow "good farming practices." Note that the coefficient estimate on the insurance dummy is not statistically different from zero at the 10 percent level; however, the marginal effect is. Respondents whose soybean fields were located in more northern areas used fungicides less frequently than producers in more southern areas, likely because rust confirmations occurred much more often in southern counties. Accounting for the impact of latitude, producers whose soybean fields were located in counties in which rust was confirmed in 2006 were more likely to use fungicides than producers in counties without a rust confirmation. However, the likelihood of using a fungicide increased by only 0.03 for producers in the former group.

Over 56 percent of the respondents reported that the most influential source of external information used to inform pest-management decisions was from their farm-supply or chemical dealer. Concerns have been raised that information from these sources would somehow unduly influence the use of expensive fungicides; however, although the likelihood of fungicide use increased for these producers, the coefficient estimate and marginal effect are not statistically different from zero at the 10 percent level. None of the external sources of information used by soybean producers to inform pest-management decisions included in the model had a statistically significant impact on fungicide use, including information received from independent crop consultants. Although the coefficient estimate on the independent-crop-consultant dummy variable is statistically different from zero at the 10 percent level, the relatively minor, marginal effect on fungicide use is not.

PIPE Website Visitation and Changes in the Management of Fungicide Use

In this section, the relationship between the management of fungicide use, website visitation, and probability beliefs is examined to test Roberts et al.'s (2006, 2009) hypothesis that the information reported on the PIPE website is more likely to lead to a change in the rust-management behavior of soybean producers who are ambiguous about their chances of experiencing a rust outbreak relative to producers who are more certain about their chances. In the following, respondents who reported believing rust was somewhat likely, uncertain, or somewhat unlikely are assumed to have had ambiguous probability beliefs, and respondents who reported believing rust was either very likely or very unlikely are assumed to have had "certain" beliefs. On the field-level questionnaire, producers were asked whether they visited

[5] The information reported on the website both increases and decreases the likelihood that soybean producers apply a fungicide when they should and should not, respectively; therefore, the impact of website visitation on the likelihood of fungicide use is unclear and will vary annually and regionally. A website-visitation dummy was included in a version of the model not reported in Table 4. Neither the coefficient estimate, 0.11 (s.e. = 0.13), nor the marginal effect, 0.007 (s.e. = 0.009), were statistically different from zero at the 10 percent level; and inclusion of the dummy variable did not alter the signs or magnitudes of the other coefficient estimates.

Table 4. Maximum Likelihood Estimates for Probit Model of Fungicide Use

Dependent variable	= 1 if farmer applied a fungicide to manage rust				
Observations	1,884				
Iterations	44				
Log likelihood value (L_u)	-321.29				
Restricted log likelihood (L_r)	-413.62				
-2(L_r–L_u)	184.66 ***				
Variable	Coefficient	Std. error	Marginal effect	Std. error	Mean
intercept	2.6496 ***	0.7586	0.1632 ***	0.0456	
age of operator	-0.0108 **	0.0052	-0.0007 **	0.0003	53.47
= 1 if operator had some college	0.0490	0.1106	0.0030	0.0068	0.54
= 1 if debt-to-asset ratio ≥ 0.4	-0.0871	0.1139	-0.0055	0.0073	0.62
= 1 if gross value of sales ≥ $500,000	0.5292 ***	0.1118	0.0383 ***	0.0092	0.37
= 1 if purchased federal crop insurance	0.2252	0.1480	0.0123 *	0.0073	0.78
latitude of the surveyed field	-0.1143 ***	0.0171	-0.0070 ***	0.0011	39.93
= 1 if rust confirmed in operator's county	0.4189 ***	0.1331	0.0342 **	0.0143	0.16
= 1 if the most influential source of external, pest-management information was from a ...					
... farm-supply or chemical dealer	0.1271	0.1791	0.0066	0.0087	0.56
... extension advisor	0.1757	0.1980	0.0097	0.0105	0.21
... independent crop consultant	0.4064 *	0.2266	0.0283	0.0176	0.07
... other growers or producers	0.3671	0.3556	0.0246	0.0299	0.03

Notes: Data are from the 2006 field- and farm-level ARMS questionnaires of soybean producers. Estimates are significant at the 0.01***, 0.05**, and 0.1* levels. The likelihood ratio test statistic is chi squared, with 11 degrees of freedom, under the null hypothesis that all slope coefficients are zero. For a dummy variable, the marginal effect is the change in the estimated probability that the dependent variable is one, when the dummy variable is one and zero, with the remaining variables evaluated at their means. The marginal effect of an external, pest-management–information dummy is computed similarly; however, because these are mutually exclusive dummy variables, the other information dummies are set to zero, as opposed to their sample means. For a continuous variable, or the intercept, the marginal effect is the derivative of the estimated probability that the dependent variable is one with respect to the variable, with all variables evaluated at their means. The standard errors for the marginal effects were computed using the delta method (Greene 2008).

the PIPE website; respondents who reported that they had visited the website were subsequently asked whether the information they found caused them to change their management of fungicide use. Of the 3,042 usable, field-level questionnaires, 478 soybean producers reported visiting the website, and of those, 263 and 215 reported having "ambiguous" and "certain" beliefs, respectively. Of the 263 producers with ambiguous probability beliefs, 22 (8.37 percent) reported changing their management of fungicide use after visiting the website, and of the 215 producers with "certain" beliefs, nine (4.19 percent) reported changing their management of fungicide use. The hypothesis that these percentages are equal can be rejected at the 10 percent level ($z = 1.85$, $p = 0.06$) using a two-proportion z-test, which provides empirical support for Roberts et al.'s (2006, 2009) hypothesis. Almost identical results are obtained by estimating a standard, probit model.[6]

To test and account for bias potentially resulting from using the non-random sample of respon-

[6] Using the 478 observations, the dependent variable was one or zero for respondents who changed or did not change their management of fungicide use because of information found on the website, respectively. The marginal effect of having ambiguous probability beliefs in the probit model's estimates is 0.0418 (s.e. = 0.0219, $p = 0.056$).

dents who visited the website (Heckman 1979), the following bivariate, probit model is examined:

$$(2) \quad \begin{aligned} & y_1 = 1 \text{ if } y_1^* = \mathbf{x}_1'\beta_1 + \varepsilon_1 > 0 \\ & y_2 = 1 \text{ if } y_2^* = \mathbf{x}_2'\beta_2 + \varepsilon_2 > 0, \text{ where} \\ & \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right], \text{ and} \\ & y_1 \text{ is observed only when } y_2 = 1. \end{aligned}$$

In this model, y_2 is one or zero if the respondent visited or did not visit the website, respectively, and y_1 is one or zero if the respondent changed or did not change the management of fungicide use as a result. Therefore, y_1 is observed only when y_2 is equal to one. The independent variables used to explain website visitation, $\mathbf{x}_2$, are the same variables examined earlier (Table 3); however, the separate probability-belief dummy variables are replaced by a single variable, which is one or zero depending on whether the respondent reported having had ambiguous or certain probability beliefs, respectively. $\mathbf{x}_1$ contains an intercept and the latter dummy variable. The disturbance terms, ε_1 and ε_2, are assumed to have a bivariate, standard-normal distribution, with a correlation coefficient given by ρ. Empirical support for the presence of sample-selection bias is obtained when the estimate of ρ is statistically different from zero.

In the results reported in Table 5, the marginal effect is given by the change in the expected value of y_1 conditional on visiting the website, $\mathrm{E}[y_1 \mid y_2 = 1]$, which is the sum of the indirect effect on website visitation and the direct effect on whether the management of fungicide use changed as a result. Because the estimate of ρ is not statistically different from zero at the 10 percent level, the data do not support the presence of sample-selection bias. Nevertheless, the coefficient estimates on the ambiguous-belief dummy are statistically significant and positive in both of the index equations, and the marginal effect of having had ambiguous probability beliefs is positive and statistically significant at the 5 percent level. Holding ambiguous probability beliefs at the beginning of the 2006 growing season increased the likelihood that the respondent visited the PIPE website and the likelihood that the respondent changed the management of fungicide use as a result relative to holding certain probability beliefs. Although the marginal effect—a 0.06 increase in the likelihood of modifying behavior—might be considered a relatively minor quantitative impact, it is important to assess its level in accordance with the relative absence of rust during 2006 in areas where the majority of U.S. soybeans are produced.

The two-proportion *z*-test examined above applied to the merged field- and farm-level data provides almost identical results. Of the 1,884 usable questionnaires, 317 soybean producers reported visiting the website and, of those respondents, 184 and 133 reported having ambiguous and certain probability beliefs, respectively. Of the 184 soybean producers with ambiguous probability beliefs, 18 (9.78 percent) reported changing their management of fungicide use after visiting the website and, of the 133 producers with certain probability beliefs, five (3.76 percent) reported changing their management of fungicide use. The hypothesis that these percentages are the same can be rejected at the 5 percent level ($z=2.04$, $p=0.04$).

Conclusions

The goal of this article is to improve current understanding of the factors that help to determine the value of the information reported on the USDA PIPE website and, more generally, the value of plant disease early-warning systems. To motivate the analysis, recent data are used to estimate aggregate fungicide costs and the geographic extent and severity of rust epidemics since the fungal pathogen, *P. pachyrhizi*, was introduced. The estimates suggest that aggregate impacts were lower than projected previously. However, the analyses conducted by Livingston et al. (2004) and Johansson et al. (2006), before those data were available, examined the potential impacts of an established *P. pachyrhizi* population, which recent data also suggest has yet to occur.

Because the value of the information reported on the PIPE website has been shown to depend on soybean producers' subjective beliefs about the probability of experiencing a rust outbreak (Roberts et al. 2006, 2009), the remainder of the article examines recent survey data to improve understanding of the factors that determine probability beliefs, the relationship between PIPE website visitation and probability beliefs, the use of fungicides to control rust, and whether information

Table 5. Maximum Likelihood Estimates of Bivariate Probit Model Relating Website Visitation and Probability Beliefs to Changes in the Management of Fungicide Use

Observations	1,884				
Iterations	19				
Log likelihood	-892.11				
Variable	Coefficient	Std. error	Marginal effect	Std. error	Mean
Changed management of fungicide use as a result of information found on the PIPE website					
intercept	-1.6648 *	0.8753			
= 1 if believed rust was somewhat likely, uncertain, or somewhat unlikely	0.4679 *	0.2525	0.0595 **	0.0274	0.58
Visited the PIPE website					
intercept	-1.2209 ***	0.2235			
age of operator	-0.0038	0.0036	-2.85E-05	0.0002	53.47
= 1 if operator had some college	0.3492 ***	0.0738	0.0026	0.0198	0.54
= 1 if debt-to-asset ratio ≥ 0.4	-0.1541 ***	0.0742	-0.0011	0.0087	0.62
= 1 if gross value of sales ≥ $500,000	0.4017 ***	0.0726	0.0030	0.0228	0.37
= 1 if spouse's occupation off-farm	0.1010	0.0733	0.0008	0.0058	0.46
= 1 if believed rust was somewhat likely, uncertain, or somewhat unlikely	0.2646 ***	0.0709			0.48
Disturbance correlation					
correletation coefficient, ρ	-0.0717				

Notes: Data are from the 2006 field- and farm-level ARMS questionnaires of soybean producers. Estimates are significant at the 0.01***, 0.05**, and 0.1* levels. The marginal effects account for the effect of the independent variable on website visitation and the change in the management of fungicide use. For a dummy variable, the marginal effect is the change in the estimated probability that the respondent changed the management of fungicide use as a result of information found on the PIPE website, when the dummy variable is one and zero, with the remaining variables evaluated at their means. For a continuous variable, or the intercept, the marginal effect is the derivative of the estimated probability with respect to the variable, with all variables evaluated at their means. The standard errors for the marginal effects were computed using the delta method (Greene 2008).

found on the website is more likely to modify the management behavior of producers who are ambiguous about their chances of experiencing a rust outbreak relative to producers who are more certain. The analysis suggests that the latitude of the farm is the most important determinant of a soybean producer's probability beliefs. Respondents who operated farms in more northern locations were less likely to believe a rust outbreak was very likely, somewhat likely, or uncertain, and more likely to believe a rust outbreak was very unlikely. These and other estimates suggest that the respondents were knowledgeable about the characteristics of soybean rust and that previous efforts to make information about rust publically available were successful.

The analysis also indicates that respondents who believed a rust outbreak was very likely, somewhat likely, uncertain, or somewhat unlikely visited the PIPE website more frequently than respondents who believed a rust outbreak was very unlikely. This suggests that probability beliefs affect the likelihood that information reported on the PIPE website is received directly and, more generally, that agricultural producers who believe they are facing similar management issues will visit websites maintained by USDA, or other governmental agencies, in conjunction with plant disease or invasive species early-warning systems. Respondents with some college experience and respondents with less debt and more income were more likely to visit the website than respondents without college experience and respondents with more debt who earned less. This suggests that, by reducing the costs of Internet access in rural areas, the USDA Rural Development Broadband Program might increase access to the website and improve the ability of more U.S. soybean producers to manage rust more efficiently.

Measures of financial well-being had negligible impacts on the likelihood of fungicide use, which suggests that soybean producers were not financially constrained. Respondents who purchased federal crop insurance were slightly more likely to use fungicides than producers who did not, likely because the receipt of an indemnity in the event of a rust outbreak requires producers to follow "good farming practices." As expected, respondents whose soybean fields were located in more northern areas used fungicides less frequently than producers in more southern areas, and respondents whose soybean fields are located in counties in which rust was confirmed were more likely to use fungicides than producers in counties in which rust was not confirmed. Additionally, the results do not support the notion that information from farm-supply or chemical dealers unduly influenced the use of expensive fungicides in 2006.

Several statistical methods were used to provide empirical support for the primary implication of the analysis conducted by Roberts et al. (2006, 2009), which holds that individuals who are more ambiguous about their chances of experiencing a rust outbreak are more likely to modify their management of fungicide use after visiting the website than producers who are more certain about their chances. The current analysis provides empirical support for their estimates of the value of information reported on the PIPE website and strongly suggests that probability beliefs affect the value of the information reported by plant disease early-warning systems more generally by increasing the rate at which they are accessed and the rate at which the information reported leads to a change in management.

These results suggest that information reported on the PIPE website, and by plant disease early-warning systems in general, is valued more highly by agricultural producers who are ambiguous about their chances of experiencing a disease outbreak. The results indicate that, in the case of soybean rust, producers who hold such beliefs are much more likely to operate farms in the south than in the north. Along with the results examining the determinants of website visitation, the policy implications of the current analysis are clear. Reducing the costs of Internet access in southern areas, in particular, would increase the aggregate value of the PIPE website, by making the information more directly available to the soybean producers who value it most.

References

Casella, G., and R.L. Berger. 1990. *Statistical Inference*. Pacific Grove, CA: Brooks/Cole Publishing Company.

Dorrance, A.E., M.A. Draper, and D.E. Hershman (eds.). 2007. "Using Foliar Fungicides to Manage Soybean Rust." Publication No. SR-2008, Land-Grant Universities Cooperating NCERA-208 and OMAF, Ohio State University, Columbus, OH. Available at http://www.ksre.ksu.edu/library/plant2/mf2680.pdf (accessed March 8, 2010).

Dubman, R.W. 2000. "Variance Estimation with USDA's Farm Costs and Returns Surveys and Agricultural Resource Management Study Surveys." Staff Paper No. AGES 00-01, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

Greene, W.H. 1993. *Econometric Analysis* (2nd edition). New York: Macmillan Publishing Company.

____. 2008. "Discrete Choice Modeling." In T. Mills and K. Patterson, eds., *Handbook of Econometrics* (Vol. 2): *Applied Econometrics*. London: Palgrave.

Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47(1): 153–161.

Johansson, R.C., M.J. Livingston, J. Westra, and K. Guidry. 2006. "Simulating the U.S. Impacts of Alternative Asian Soybean Rust Treatment Regimes." *Agricultural and Resource Economics Review* 35(1): 116–127.

Livingston, M.J., R.C. Johansson, S. Daberkow, M.J. Roberts, M. Ash, and V. Breneman. 2004. "Economic and Policy Implications of Wind-Borne Entry of Asian Soybean Rust into the United States." Outlook Report No. OCS04D02, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

Pivonia, S., and X.B. Yang. 2004. "Assessment of the Potential Year-Round Establishment of Soybean Rust throughout the World." *Plant Disease* 88(5): 523–529.

Roberts, M.J., D. Schimmelpfennig, E. Ashley, and M.J. Livingston. 2006. "The Value of Plant Disease Early-Warning Systems: A Case Study of USDA's Soybean Rust Coordinated Framework." Economic Research Report No. 18, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

Roberts, M.J., D. Schimmelpfennig, M.J. Livingston, and E. Ashley. 2009. "Estimating the Value of an Early Warning

System." *Review of Agricultural Economics* 31(2): 303–329.

U.S. Department of Agriculture. 2006. "A Coordinated Framework for Soybean Rust and Aphid Surveillance, Reporting, Prediction, Management and Outreach." Animal and Plant Health Inspection Service, USDA, Riverdale, MD. Available at http://www.ipmpipe.org/SC/A%20Coordinated%20Framework%20for%20Soybean%20Rust%20and%20Aphid%20-%205-1-06.pdf (accessed on January 7, 2010).

____. 2008. *Agricultural Statistics 2008*. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C.

____. 2009. *Quick Stats*. National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, D.C. Available at http://www.nass.usda. gov/ (accessed January 7, 2010).

U.S. Government Accountability Office (USGAO). 2005. *USDA's Preparation for Asian Soybean Rust*. Publication No. GAO-05-668R, USGAO, Washington, D.C.