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Abstract: The spread of Asian Soybean Rust (ASR) represents a real threat to the U.S. soybean sector. We assess the potential impacts of ASR on domestic soybean production and commodity markets as well as the competitive position of the US in the soybean export market. We develop a mathematical stochastic dynamic sector model with endogenous prices to assess the economic impacts of ASR on US agriculture. The model takes into account the disease spread during the cropping season, the inherent uncertainty regarding the risk of infection, and the dichotomous decisions that farmers make (no treatment, preventive treatment, and curative treatment) facing the risk of infection. Our results suggest substantial impacts from potential ASR spread on agricultural output, prices and exports. Our simulation results suggest that substantial losses to the US soybean producers may be avoided by establishing effective soybean rust controls. ASR control policies can be particularly efficient if applied in the gateway regions on the path of the ASR spread. On the other hand, our results indicate a possible gradual shift in soybean production from lower-latitude states toward higher-latitude states.

Keywords: Asian Soybean Rust, Stochastic Models, Dynamic Models

JEL: C61, Q13

Introduction

Asian Soybean Rust (ASR) is among the most severe foliage diseases of soybeans. It spreads rapidly and can reduce yields drastically (Miles, Frederick, and Hartman 2003). In the US it was first detected in Southern Louisiana in 2004 and experts believe that its spores were brought by summer storm winds originating in South America. Since then, it has been observed in soybeans and kudzu (an important ASR host plant for its spores) in several Southern coastal states, including Alabama, Florida, Georgia, Mississippi and Texas (USDA 2009). ASR has also been a major threat to farmers in South America since 2001. It has been present in Argentina since 2002 and by 2005 it had spread to virtually all production regions in the country. In 2004 soybean output in Brazil dropped by nearly 5% due to ASR infection. The US, Argentina and Brazil are the main suppliers of soybeans in world markets, with a total share of more than 90% in international markets. Therefore, a significant change in the supply of any of these countries may have serious impacts on domestic commodity and livestock markets and in international soybean markets.

The spread of ASR represents a real threat to the U.S. soybean sector and warrants the its strict surveillance. Consequently, in 2005 the U.S. Department of Agriculture initiated a sophisticated Soybean Rust Coordinated Framework to monitor and control the spread of the disease. The premise for creating this coordinated framework is that publicly provided information creates value by allowing farmers make better decisions regarding actions for the control and prevention of ASR infection (Roberts and Schimmelpfennig 2006). Information about ASR spread in the United States is communicated through various channels including an interactive website in which users can observe daily maps of ASR incidence, education on management strategies to control spread of the disease, links to recent research findings on ASR, and expert advice as to possible disease spread patterns. The framework contributes to coordinate communication between individuals monitoring ASR in sentinel plots and soybean production areas, government officials, academic researchers and stakeholders (Roberts and Schimmelpfennig 2006).

In spite of its potential negative impacts and the current government-led efforts to control ASR spread, relatively little is known about the potential economic impacts of ASR in the U.S. soybean sector. Nevertheless, agricultural economists started to evaluate the economic impacts of ASR in recent years, as data on disease spread patterns and possible control strategies became available. For instance, Johansson et al. (2006) examines the impact of alternative scenarios for spread of ASR in the US and find increased prices and substantial reductions in soybean production and exports. Bekkerman et al. (2008) conducts a risk analysis that takes into account spatial and temporal correlations to price possible annual insurance contracts to cover soybean rust damages. This study contributes to the empirical literature on ASR's economic impact assessment by developing a stochastic dynamic model in which prices are endogenous. Our study contributes incorporate the patterns of ASR dispersion into impact assessment as well as the subsequent welfare implications.

The primary objective of this study is to assess the impacts of ASR on domestic soybean production and commodity markets as well as the competitive position of the US in the soybean export market. Our hypothesis is that an effective control of the spread of ASR domestically may protect US soybean producers against production losses and may also improve the competitive position of U.S. in the export markets. The ASR influences agricultural production in several ways. It may reduce yields, which can be drastic unless adequate preventive measures are taken; increase production costs (due to additional fungicide applications); and make farmers switch to alternative crops (to reduce production risk). All these factors are likely to alter the equilibria in commodity markets. Moreover, changes in crop patterns are expected to vary across regions due to the comparative advantage of individual regions in producing alternative crops.

This article is organized as follows. The next section reviews earlier literature on the economic impacts of plant disease in general and ASR in particular. The third section describes the stochastic dynamic programming model to study ASR impacts and the fourth section described the data employed to calibrate the model. The fifth section discusses the results and the last section concludes and proposes areas for future research.

Literature Review

Plant disease risks and economic approaches

Plant diseases are becoming increasingly important in the design of domestic and international policies affecting food and agriculture. Plant health issues as well as the resulting policies in response to plant disease challenges may impact food security, international trade, economic welfare and sector performance. Consequently, governments are making efforts in data collection to detect and monitor the spread of plant diseases. The increasing amount of data available together with the wide variety of economic issues related to plant diseases have attracted the attention of agricultural economists interested in assessing the economic costs of plant diseases and in identifying appropriate strategies to eliminate or contain disease spread.

Oude Lansink (2007) summarizes recent research advances in the study of economic impacts of plant disease. At the heart of these new approaches is how to respond optimally to a plant disease-related problem with inherent risk and uncertainty. A stream of research focuses on the costs and benefits of phytosanitary measures to avoid or control disease spread such as pre-emptive actions, continuous monitoring and scouting, border inspections, and curative actions to control disease. For instance, Moffit et al. (2007) combines an info-gap model and the principle of stochastic dominance to develop a robust inspection strategy when inspections budgets are limited. Surkov et al. (2007) develops a conceptual model to allocate scarce resources in the context of quarantine risks related to the international trade of agricultural products. They find that more effective risk reductions can be achieved by allocating greater resources to the inspection of riskier disease paths; and smaller resources to inspection of less risky pathways.

Spatial models have been employed to evaluate the risks and economic impacts of disease spread. Goodwin and Piggott (2007) constructs a spatiotemporal model to quantify the risk of Asiatic citrus canker disease for commercial producers of oranges in Florida. The authors employ a large database of inspections spanning the period 1998-2004 to estimate probit and

Poisson regression models. Based on their parameter estimates, the authors develop a risk model that contributes to determine the value of insurance contracts for protection against the disease. In the same spirit, Acquaye et al. (2007) employs a partial equilibrium framework to evaluate the economic impact of hurricanes on the spread of Asiatic citrus canker disease and the subsequent eradication policy in Florida. The model takes into account the spatial and temporal aspects or disease spread as well as the costs and benefits of the eradication policy. The authors show that farmers' welfare increases from Asian citrus cancer and from the eradication policy at the expense of reduced economic welfare from other sectors in society. Breukers et al. (2007) focus on the spread of brown-rot potato disease in the Netherlands. Their approach combines an epidemiological stochastic model that simulates the spatial spread of brown-rot disease and an economic model of the private costs of efforts to contain the disease. They find that low monitoring efforts are more efficient if the product is offered in domestic markets. In contrast, high monitoring efforts are desirable if the product is intended for the international market.

Another stream of research focuses on the non-monetary impacts of phytosanitary policies. Researchers have developed methods to elicit stakeholder willingness to pay (WTP) for measures to control disease spread. Areal and Macleod (2007) investigate the WTP for trees at risk of infection from *Phytophthora ramorum*, a disease that cause sudden oak death. The authors use a discrete choice model and a double-bound bid likelihood function and find that the average WTP of the British taxpayer for disease control is about 55 pound per year over a five-year period. Mourits and Lansink (2007) take a broader approach to assess the impact of phytosanitary regulation. They employ a tool called Multi-Criteria Decision Making, which allow them to integrate such disease-relater aspects as epidemiology, economic and ethical. They show the value of using this tool to assess various strategies to control animal quarantine diseases in animals.

Overall, these studies emphasize the importance of modeling the stochastic nature of plant disease spread as well as the spatiotemporal patterns of disease dispersion when evaluating alternative policies and private strategies for disease control. At the same time, this literature stresses the need to quantify the costs and benefits of phytosanitary measures that affect agricultural sectors.

Soybean Rust in the United States

Five years ago, when ASR was first detected in the United States, policy makers and agricultural economists started to examine potential economic impacts of ASR, given the importance of the soybean sector in the country. Roberts and Schimmelpfennig (2006) examine the value of publicly available information about ASR versus the costs of USDA's Soybean Rust Coordinated Framework initiated in 2005. The authors show that the costs accrued to the framework are much lower than the value of the information provided. For farmers who face potential ASR infection, information about the likelihood of disease occurrence can help them make better decisions about the amount and timing of fungicide applications, which will ultimately increase their profits.

Relatively little research has been conducted on the economic impacts of ASR in the US soybean sector, in part because it was first detected in Louisiana quite recently. To our knowledge, only two studies have addressed the economic impacts of ASR spread in the US (Johansson et al. 2006; Bekkerman et al. 2008). Johansson et al. (2006) conducts an early assessment of ex-ante ASR impacts by considering alternative scenarios for spread and control of the disease in the US. The authors examine economic consequences of three possible ASR impact scenarios on production costs and yields: do nothing, apply a preventive fungicide treatment, and apply a curative fungicide treatment. The authors use a regional linear programming model developed by USDA's Economic Research Service to simulate the regional yield and cost impacts and the subsequent changes in equilibrium prices and quantities (Livingston et al. 2004). Their model assumes an adjustment period of five years so the expected impacts are calculated for a steady state in 2010. The authors develop a partial equilibrium model of the US agricultural sector considering forty five geographic regions and the markets for twenty three agricultural inputs including labor, land and water, among others. The model is calibrated employing data on the spatiotemporal distribution of ASR, on the spread patterns of other similar wheat and corn diseases that have occurred in the past, and on the available information regarding the costs of fungicides necessary for disease control. Their results suggest that economic impacts of ASR may be higher than expected in earlier assessments and will likely result in smaller soybean harvests, reduced exports, and increased prices by 2010. Specifically, the authors find that losses to US agriculture are lowest with a curative fungicide application strategy, followed by the no-treatment strategy. The preventive fungicide application strategy results in the highest losses for US agriculture. The authors, however, point out to that the restrictive assumptions of their model suggest that uncertainty about ASR impacts remain and more studies are necessary to evaluate, ex-ante, the potential impacts of this disease for US agriculture.

More recently, Bekkerman et al. (2008) considers the economic impacts of ASR in the context of risk and severity analysis to quantify the risk of ASR infection and to simulate possible prices of ASR-related insurance contracts or indemnification programs. The authors use data from the disease inspection and monitoring program established by the USDA and information about climatological and biological factors to develop a model of the risks of ASR infection in the United States. In turn, the results from these risks models are used to calculate fair premium rates for insurance policies conditional to the severity of crop losses. The study uses over 35,000 field-level inspections spanning the period 2005-2007, and includes county-level weather statistics, planting dates and maturity groups from various sources. The econometric model of ASR risk infection is aggregated at the county level and the parameter estimates are obtained from alternative models, including simple probit, zero-inflated Poisson and negative binomial models. The authors provide a careful treatment of the endogeneity that may exist between inspections and ASR findings. The conditional probabilities of ASR infection estimated above are employed to compute expected losses and the subsequent fair premiums of insurance contracts. The results indicate a high degree of variability in ASR infection probabilities and in the corresponding insurance premiums across soybean production regions in the United States. The estimated average premium rates are lower in northern regions (1.59%) and higher in southern regions (27.66%). The authors point out the need to do further research to understand the links between economic impacts and spread patterns of ASR.

Overall, the growing the applied economics literature indicates a high degree of uncertainty regarding the impacts of ASR infection on the US agricultural sector. Our study contributes to this literature emerging by developing a mathematical stochastic dynamic sector model with endogenous prices to assess the economic impacts of ASR on US agriculture. The model takes into account ASR spread during the cropping season, the inherent uncertainty regarding the risk of infection, and the dichotomous decisions that farmers make facing the risk of disease spread.

Model

ASR influences agricultural production in several ways. It may reduce yields, which can be drastic unless adequate preventive or curative measures are taken, increase production costs (due to additional fungicide applications), and make farmers switch to alternative crops (to reduce production risk). All these factors are likely to alter the equilibria in commodity markets. Changes in crop patterns are expected to vary across regions due to the comparative advantage of individual regions in producing alternative crops.

In order to address the research issues stated above, we develop a multi-market, multi-product spatial equilibrium model where market prices are determined endogenously employing the well known social-surplus maximization approach (Takayama-Judge, 1971; McCarl and Spreen, 1980). Consumer demand is incorporated via national demand functions for major commodities and a detailed supply response component simulates the allocation of land among crops, technology choices, and resource utilization at a spatially disaggregate level. We formulate the US soybeans production component of the model as in discrete stochastic programming considering three periods during the growing season, where appearance of the ASR in any region and time period is stochastic and optimal fungicide application in each region and time period depends on what happens in the ‘upstream’ region on the path of ASR. To do this, we follow the surveillance system established by the USDA in 2004, which shows that the spread of ASR follows a path from the Gulf States early in the cropping season and moves to the north as far as Minnesota around September.

Our model maximizes a profit function for corn, soybeans and wheat, which are the three main crops in the Corn Belt region. The model also includes a profit function for soybean meal, and soybean oil, the primary products resulting from the industrial processing of soybeans. We include the demand of all these commodities for human consumption, for feed consumption, and consumption in international markets. On the other hand, the model takes into account production detailed production costs related to planting and harvesting foe all crops and rotations and soybean crushing costs (to obtain soybean meal and soybean oil).

The optimization model includes several restrictions that account for the balance between demand and supply of commodities; the balance between export supply and import demand in the rest of the world; the limited amount of agricultural land available for commercial production; the historical crop mixtures to smooth the changes in production structures over time; and the amount of commodity inventories. In addition, the model takes into account common rotation practices employed in agricultural production at the state level as well as the strategy to produce two harvests of soybeans in a given year that is often employed in the Midwestern region.

Based on recent literature, we employ the following assumptions in the development of our stochastic dynamic programming model of ASR spread (Roberts et al. 2006; Rossman 2008; Robinson 2005; Mueller et al. 2006; Mueller et al. 2006; Sweets et al. 2004; Livingston et al. 2004; Isard et al. 2005; Isard et al. 2007; Integrated Aerobiology Modeling System 2009):

- ASR is permanently present in the southern region of the United States (Texas, Louisiana, Mississippi , Alabama, Georgia, North Carolina) because the climatic conditions in this region are conducive to ASR overwinter; subsequently, as spring progresses, the disease starts to spread toward central region (Arkansas, Tennessee, North Carolina, Kentucky); and it continues moving gradually toward the Northern region of the Midwest (Iowa, Illinois, Minnesota, Indiana, Nebraska, Ohio, Missouri, South Dakota, North Dakota, Kansas, Michigan, Wisconsin). It is believed that ASR cannot overwinter in the Central and Northern regions of the Unite States; it moves from the Southern states to the north during the cropping season, depending on the climatic conditions.

- Farmers can avoid ASR infection by applying preventive fungicide in the first two reproductive stages of the soybean crop in the cropping season.
- Farmers that do not apply preventive fungicide treatment have 80% probability of ASR infection; they apply curative fungicide treatment and are not affected by ASR in the remaining of the cropping season; however, their yield loses are about 25% at harvest.
- Farmers in the Central and Northern regions observe if ASR infections occur in the adjacent region to the South (the Central region sees ASR infections the Southern region, and the Northern region see ASR infection in the Central region); consequently we consider two cases: 1) if the amount of land in the southern region with ASR is less than 5% out of the total soybean land planted, then a farmer in the contiguous region has a “low risk” of infection and do not need to apply preventive fungicide; and 2) if 5% or more of the soybean land if infected, farmers are in “high risk” of ASR infection so they have to decide whether or not to apply preventive fungicide.
- Farmers in the Southern region plant soybeans two weeks earlier than farmers in the Central region; and farmers in the Central region plant soybeans two weeks earlier than farmers in the Northern region. Therefore, farmers in the Central and Northern regions make decisions after observing ASR infection in the adjacent region.

Based on these assumptions, we develop a stochastic model of three distinct regions (South, Central and North) and three time periods during the cropping season. The problem is to maximize a profit function of the agricultural regions in the study. This profit function includes the costs for both preventive and curative fungicides. On the other hand, our model punishes the yield of the land that exhibits ASR infection (which coincides with the land in which curative fungicide treatments were applied). The Mathematical Stochastic Dynamic and Price Endogenous sector model for the Asian Soybean Rust in US is specified as follows:

Objective Function: Maximize the value of total domestic demand for food and feed goods, and world demand for goods; minus production and harvesting costs; minus export costs; minus crush costs (for soybeans only); minus fungicide costs (for soybeans only):

$$
\begin{aligned}
(1) \qquad & \sum_{fo} H_{fo}(\alpha_{fo} - 0.5\beta_{fo} H_{fo}) + \sum_{fe} F_{fe}(\alpha_{fe} - 0.5\beta_{fe} F_{fe}) \quad + \sum_{g} E_g(\alpha_g^{\exp} - 0.5\beta_g^{\exp} E_g) \\
& - \sum_{s}\sum_{Cr} \mathrm{c}_{Cr,s}^{production} * Planted_{Cr,s} - \sum_{g} \mathrm{c}_g^{export} * E_g - \quad \mathrm{c}_{soy}^{crush} * Crush \\
& - \sum_{s}\sum_{t} \mathrm{c}^{CF} * (X_{s,t}^{SR} - X_{s,t-1}^{SR}) \text{-} \sum_{s}\sum_{t} \mathrm{c}^{F} * X_{s,t}^{F}
\end{aligned}
$$

Restrictions:

i) Market clearing conditions: Domestic demand for food and feed goods; plus world demand for goods; plus Final commodities stocks must equal production of commodities plus initial commodities stocks.

(2) For corn and wheat: $H_{fo} + F_{fe} + E_g + Stock_{Cr}^{final} \leq \mathrm{Production}_c + Stock_{Cr}^{initial}$

(3) For soybean: $Crush + Stock_{Soybean}^{final} \leq \mathrm{Production}_{Soybean} + Stock_{Soybean}^{initial}$

(4) For soybean meal: $F_{Soybean\ meal} + E_{Soybean\ meal} \leq 0.8 * Crush$

(5) For soybean oil: $H_{Soybean\ oil} + E_{soybean\ oil} \leq 0.17 * Crush$

ii) Supply and demand balance restrictions:

(6) For corn and wheat: $$\text{Production}_c = \sum_s y_{c,s} * Survival\_rate_{c,s} * Planted_{c,s}$$

(7) For soybeans: $$\text{Production}_{soybean} = \sum_s rust\_y_{soybean,s} * Survival\_rate_{soybean,s} * X^{SR}_{s,T} + \sum_s y_{soybean,s} * Survival\_rate_{soybean,s} * X^{NSR}_{s,T}$$

iii) Exports balance: Total US exports equal the sum of exports by region

(8) $$E_g \leq \sum_s E_{g,s}$$

iv) Land available restriction: Total planted equals total land available (by State)

(9) $$\sum_{Cr} Planted_{Cr,s} \leq land\_av_s \qquad \forall s$$

v) ASR treatment decision: A critical component of the model relates to the farmer's decision of applying or not applying preventive fungicide treatment, which depends on ASR infection in the contiguous region. Let *i* be the region and *t* the period, *S* and *U* are slack variables, *m* is an arbitrary large number, and *Z* is a binary variable. This decision depends on whether or not the amount of land with ASR in the adjacent state is greater than a threshold[1] of the total soybean land planted. If it is greater Z = 1, otherwise Z = 0. The equations representing these decisions are:

(10) $$\begin{aligned} &X^{SR}_{s-1,t} + S_{s,t} = Treshold * X_{s-1} + U_{s,t} \qquad s > 1 \quad \wedge \quad \forall t \\ &S_{s,t} \leq m(1 - Z_{s,t}) \qquad s > 1 \quad \wedge \quad \forall t \\ &U_{s,t} \leq mZ_{s,t} \qquad s > 1 \quad \wedge \quad \forall t \\ &Z_{s,t} \geq Z_{s,t-1} \qquad s > 1 \quad \wedge \quad t > 1 \end{aligned}$$

vi) Land to allocate either to apply preventive fungicide or do anything:

---

[1] This threshold is region-specific. This means that each region has a unique probability of ASR infection, depending on such climatic conditions as temperature, humidity and wind speed.

$$\begin{aligned}
&X_{s,t}^{F} + X_{s,t}^{NF} = X_{s} \quad \forall s \quad \wedge \quad t = 1 \\
&X_{s,t}^{F} + X_{s,t}^{NF} = X_{s,t-1}^{NSR,NF} \quad \forall s \quad \wedge \quad t > 1 \\
&X_{s,t}^{F} \leq mZ_{s,t} \quad s > 1 \quad \wedge \quad t > 1
\end{aligned} \tag{11}$$

vii) Land with ASR

$$\begin{aligned}
&X_{s,t}^{SR} = P(SR_{s,t} \mid NF_{s,t}) X_{s,t}^{NF} \qquad \forall s \quad \wedge \quad t = 1 \\
&X_{s,t}^{SR} = P(SR_{s,t} \mid F_{t-1}) X_{s,t-1}^{F} + X_{s,t-1}^{SR} + P(SR_{s,t} \mid NF_{s,t}) X_{s,t}^{NF} \qquad s > 1 \quad \wedge \quad t > 1 \\
&X_{s,t}^{SR} \leq mZ_{s,t} \qquad s > 1 \quad \wedge \quad \forall t
\end{aligned} \tag{12}$$

viii) Land without SR and without fungicide application

$$\begin{aligned}
&X_{s,t}^{NSR,NF} = (1 - P(SR_{s,t} \mid NF_{s,t})) X_{s,t}^{NF} \quad \forall s \quad \wedge \quad t = 1 \\
&X_{s,t}^{NSR,NF} = (1 - P(SR_{s,t} \mid F_{s,t-1})) X_{s,t-1}^{F} + (1 - P(SR_{s,t} \mid NF_{s,t})) X_{s,t}^{NF} \quad \forall s \quad \wedge \quad t > 1 \\
&X_{s,t}^{NSR,NF} \leq (1 - P(SR_{s,t} \mid NF_{s,t})) X_{s,t}^{NF} + m(1 - Z_{s,t}) \qquad s > 1 \quad \wedge \quad t = 1 \\
&X_{s,t}^{NSR,NF} \leq (1 - P(SR_{s,t} \mid F_{s,t-1})) X_{s,t-1}^{F} + (1 - P(SR_{s,t} \mid NF_{s,t})) X_{s,t}^{NF} + m(1 - Z_{s,t}) \qquad s > 1 \quad \wedge \quad t > 1 \\
&X_{s,t}^{NSR,NF} \leq X_{s,t}^{NF} \qquad s > 1 \quad \wedge \quad \forall t
\end{aligned} \tag{13}$$

ix) Land without SR

$$X_{s,t}^{NSR} = X_{s,t}^{F} + X_{s,t}^{NSR,NF} \qquad \forall s \quad \wedge \quad \forall t\,. \tag{14}$$

The first three equations in system (10) indicate that if ASR is greater than 5% in a given region, then *S* must be 0 and *U* must be greater than 0; otherwise *S* should be greater than 0 and *U* equal to 0 and farmers in the region do not apply fungicide treatment and wait for the following period. The fourth equation indicates that farmers decide whether or not to apply preventive fungicide because ASR was found in the previous period in the contiguous region in excess of the region-specific threshold. In this latter case the risk of infection is high.

We employ nonlinear functions for the profit equations because prices are endogenous. However, we cannot employ the nonlinear solver (NLP) in GAMS because the optimization problem involves binary decision variables and the results would not be robust. Consequently, we transform the nonlinear functions to linear approximation to solve the optimization problem using the Mix Integer Program (MIP) procedure in GAMS.

Data

The profit maximization approach described above requires a considerable amount of data. Specifically, the data requirements include commodity prices and demands at the farm gate, price elasticities of demand, world demand, world price, world price elasticities of demand, areas planted, and regional crop yields and itemized crop budgets for all producing regions. We consider three crops (corn, wheat, and soybeans), five commodities (corn, wheat, soybeans, soybean oil, and soybean meal) and three regions. We calibrate the model using regional historical data on demand and supply variables as well as an export demand for the US corresponding the aforementioned commodities and crops spanning the period 1976-2006, from twenty two US states that produce soybeans. We employ year 2006 as the baseline to conduct our simulations.

The model uses as initial values the following data: domestic demand prices for the commodities ($/bus), FOB prices ($/Bushel), total demand for commodities (bushels), exports (bushels), , area planted to each crop (Acres), area harvested from each crop (Acres), soybean crush costs ($/bushel), crop production (Bushels). In addition, we compile regional data on production costs ($/Acre), including such cost items as energy, fertilizer, chemicals, other variable costs, fix cash and capital replacement. Data regarding the costs of curative and preventive fungicides treatments are those estimated for Roberts et al. (2006).

The sources for these data are from various secondary sources including USDA's National Agricultural Statistics Service, Economic Research Service and Foreign Agricultural Service; the farm decision outreach central at the University of Illinois; the United Nations Commerce and Trade Statistics (COMTRADE) and the Food and Agriculture Organization of The United Nations (FAO).

Results

Table 1 presents results from the solution to the optimization problem described in equations (1)-(14). The first column presents the observed data in 2006. The second column presents the model output with no ASR infection, in order to assess the validity of our results through a comparison with the actual values in the first column. The third column presents the estimated impacts of ASR infection and the optimal farmer response to control ASR spread, in terms of percent changes in acres planted, production, exports and prices of soybeans, wheat and corn, relative to the no ASR infection scenario. The simulation suggests substantial economic impacts associated with ASR spread. At the national level our results indicate that soybean acreage, production and exports decrease by 13.79%, 13.10% and 20%, respectively with ASR infection. In contrast, the price per bushel of soybeans may increase by 33.93% with the disease.

[Insert Table 1 here]

The impacts of ASR on acres planted vary substantially across states. In particular, the scenario with ASR infection indicate that the most dramatic reductions in soybean acreage occur in states bordering the southern region (i.e. Missouri, Kansas and Kentucky) and in Nebraska, which is highly affected by its proximity to Texas. These states may substitute soybeans with other crops to avoid higher production costs due to additional fungicides and lower yields resulting from ASR. In contrast, under the ASR infection scenario, Northern states such as Minnesota, the Dakotas, Wisconsin, Michigan and Ohio either increase of keep the same planting levels of soybeans. Interestingly, our results show substantial differences regarding the impact of ASR in the largest soybean-producing states: soybean acreage increases by 21.12% in Iowa, decreases by 2.92% in Illinois, increases 15.26% in Minnesota, and decreases by 20.50% in Indiana.

Results in Table 1 suggest that ASR infection may influence the structure of agriculture across regions and across states. At the national level, the results show that corn acreage, production and exports may experience modest reductions with ASR, -0.14%, -0.22% and -1.30%, respectively; and corn prices could increase by 11.96%. Similarly, our simulations suggest that the wheat sector exhibits changes in the presence of ASR infection. Specifically, in the scenario with ASR, national wheat production decreases by 4.73%, exports decrease by 11.11% and wheat prices increase by 12.08%. The simulation results also indicate large changes in the structure of field crops agriculture at the state level, with general gains in acreage and production in Northern states and loses of acreage and production in Southern states.

Table 2 presents simulation results corresponding to the number of preventive and curative fungicide treatments to control for ASR spread. Our results indicate that the profit maximizing strategy consists of emphasizing preventive fungicide treatments in such Southern states as Mississippi and Louisiana (1.62 and 1.98 treatments, respectively). This result makes sense because ASR tends to overwinter in the lower Mississippi. Our results also suggest that preventive treatments should be minimized in Northern soybean production regions. For the simulation shows that The Dakotas, Michigan and Minnesota should not apply preventive fungicide treatments. In the larger soybean-producing states such as Iowa, Illinois, Ohio and

Indiana, the number of preventive fungicide applications is 0.63, which lies in between the number of preventive treatments in Northern and Southern states. The simulation indicates that there is no need to apply fungicide treatments in Missouri and Nebraska because no soybean production occurs in these states under the ASR infection scenario. This result should be considered carefully because Missouri and Nebraska are large, important soybean producing states. This finding is counter-intuitive and merits further investigation with respect to the calibration of model parameters.

[Insert Table 2 here]

Table 2 also presents the estimated number of curative fungicide treatments from the optimization model and the results are in sharp contrast with respect to the optimal number of preventive treatments. In particular, the results indicate that coastal states should not employ curative strategies for ASR control. On the other hand, the results suggest that curative ASR treatments should be emphasized in mid latitude states such as Arkansas, Ohio, Illinois, Indiana, Iowa, South Carolina and Tennessee. The highest latitude states (e.g. Minnesota and Michigan), may not require curative treatment of ASR.

Conclusions and Future Research

In this study we evaluate the impacts of ASR on domestic soybean production and commodity markets as well as the competitive position of the US in the soybean export market. It contributes to the empirical literature by developing a stochastic dynamic model in which prices are endogenous to understand the patterns of ASR dispersion in the US and its subsequent welfare implications. Our findings are useful in the design of public and private policies for ASR containment. Our simulation results suggest that substantial gains may accrue to the US soybean producers from establishing effective soybean rust controls. We also find that the ASR control policies can be particularly efficient if applied in the gateway regions on the path of the ASR spread. On the other hand, our results indicate a possible gradual shift in soybean production from lower-latitude states toward higher-latitude states, as traditionally large soybean-producing states such as Iowa, Illinois, Missouri and Nebraska bear the highest costs on preventive and curative fungicide treatments, in particular if measures to prevent spread of the disease in the Gulf States are not effective. Nevertheless, our results should be interpreted with caution because in a few instances our simulation results do not adjust to actual, reasonable expectations.

The next step of this study is extend the model to assess the impacts of ASR on domestic soybean production and commodity markets as well as the competitive position of US versus Argentina and Brazil in the soybean export market. Our hypothesis is that an effective control of the spread of ASR domestically may protect US soybean producers against production losses and may also improve the competitive position of US in the export markets. Conversely, adverse effects of ASR overseas may encourage U.S. producers to plant more soybeans in the short or medium-run given higher price expectations.

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Table 1. Impact of Asian Soybean Rust on Acres, Prices, Production and Exports

Commodity	State	Observed 2006 Acreage (1000)	Scenario without SR Acreage (1000)	Scenario with SR Acreage (1000)	% Change
Corn	AR	189.9	239.9	239.9	0.00%
	IL	11,295.2	11,166.3	11,745.0	5.18%
	IN	5,497.7	5,995.9	6,097.4	1.69%
	IA	12,594.6	13,194.4	12,815.2	-2.87%
	KS	3,348.6	3,648.4	3,648.4	0.00%
	KY	1,119.5	1,349.4	1,299.4	-3.70%
	MI	2,199.1	2,598.9	2,598.9	0.00%
	MN	7,296.9	7,496.8	7,496.8	0.00%
	MO	2,698.8	2,948.7	2,099.1	-28.81%
	NE	8,096.5	8,796.3	8,896.2	1.14%
	ND	1,689.3	1,299.3	1,689.3	30.01%
	OH	3,148.7	3,798.4	3,798.4	0.00%
	SD	4,498.1	4,294.5	4,338.1	1.02%
	TN	549.8	739.7	739.7	0.00%
	WI	3,648.4	3,748.4	3,748.4	0.00%
	Total planted	71,849.3	77,477.8	77,369.8	-0.14%
	Production (Bushels)	9,319,809.8	10,029,910.0	10,008,300.0	-0.22%
	Exports	1,982,857.8	1,665,600.6	1,643,989.7	-1.30%
	Price $/Bushel	3.4	5.0	5.6	11.96%
Soybean	AR	3,108.7	2,124.1	2,124.1	0.00%
	IL	10,095.7	9,297.3	9,026.1	-2.92%
	IN	5,697.6	4,903.3	3,898.3	-20.50%
	IA	10,145.7	8,196.5	9,927.5	21.12%
	KS	3,148.7	2,648.9		-100.00%
	KY	1,379.4	879.6		-100.00%
	MI	1,999.1	1,579.3	1,579.3	0.00%
	MN	7,346.9	5,997.4	6,912.8	15.26%
	MO	5,147.8	4,847.9		-100.00%
	NE	5,047.8	3,873.1		-100.00%
	ND	3,898.3	2,633.0	3,898.3	48.06%
	OH	4,648.0	3,808.4	3,808.4	0.00%
	SD	3,948.3	4,293.8	4,369.6	1.76%
	TN	1,159.5	649.7	649.7	0.00%
	WI	1,649.3	1,598.3	1,598.3	0.00%
	Total planted	73,268.7	59,224.9	50,949.0	-13.97%
	Production (Bushels)	3,117,240.4	2,645,123.6	2,298,603.8	-13.10%
	Exports	1,117,924.7	911,108.6	728,886.9	-20.00%
	Price $/Bushel	6.3	6.5	8.7	33.93%

Wheat					
	AR	364.8	364.8	1,299.4	256.16%
	IL	929.6	1,775.0	919.6	-48.19%
	IN	469.8	849.6	799.7	-5.88%
	IA	25.0	35.8	22.6	-37.01%
	KS	9,795.8	3,148.7	9,995.7	217.46%
	KY	429.8	749.7	749.7	0.00%
	MI	659.7	679.7	679.7	0.00%
	MN	1,749.3	1,599.3	1,983.4	24.02%
	MO	999.6	1,599.3	2,149.1	34.37%
	NE	1,799.2	1,799.2	1,999.1	11.11%
	ND	8,796.2	1,799.2	8,796.2	388.89%
	OH	989.6	1,239.8	1,179.5	-4.86%
	SD	3,308.6	3,164.2	3,047.3	-3.70%
	TN	279.9	528.1	599.7	13.57%
	WI	260.9	260.9	211.9	-18.77%
	Total	37,624.9	20,971.1	36,057.1	71.94%
	Production (Bushels)	1,178,914.1	1,416,913.0	1,349,919.8	-4.73%
	Exports	908,543.5	572,382.4	508,784.3	-11.11%
	Price $/Bushel	3.9	10.1	11.4	12.08%

Table 2. Number of Preventive and Curative Fungicide Applications

State	Optimal Number of Preventive fungicide applications	Number of curative fungicide applications
Al	0.20	0.80
AR	0.66	0.67
GA	--	--
IL	**0.63**	**0.64**
IN	**0.63**	**0.64**
IA	**0.63**	**0.64**
KS	--	--
KY	--	--
LA	1.98	0.02
MI	0.00	0.00
MN	**0.00**	**0.00**
MS	1.72	0.13
MO	**--**	**--**
NE	**--**	**--**
NC	0.66	0.67
ND	**0.00**	**0.00**
OH	**0.63**	**0.64**
SC	0.20	0.80
SD	**0.00**	**0.00**
TN	0.15	0.85
TX	0.00	0.00
WI	0.44	0.05

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