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Economic and Policy Implications of Wind-Borne Entry of Asian Soybean Rust into the United States

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Abstract

American soybean producers and the research, regulatory, and extension institutions supporting them are preparing for the potential wind-borne entry of Asian soybean rust into the United States. For the first year of the pathogen's establishment in this country, this analysis estimates that the expected value of net economic losses will range from $640 million to $1.3 billion—less than 1 percent of net economic benefits derived from agricultural activity—depending upon the geographic extent and severity of the pathogen's initial entry. Annual losses in the ensuing years could average anywhere between $240 million and $2.0 billion, depending on the severity and extent of subsequent outbreaks. The large range of damage estimates reflects the uncertainty associated with eventual effects of soybean rust in the United States. But even high-end figures are small relative to the total value of soybeans in production and consumption—a finding that confirms the resiliency and adaptability of U.S. agriculture.

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Introduction

Asian soybean rust, a plant disease caused by *Phakopsora pachyrhizi*, has lowered yields and raised production costs in many parts of the world including Asia, Australia, India, Africa, and South America (Caldwell and Laing; Yorinori et al.; Ogle, Byth, and McLean). *P. pachyrhizi* can infect over 95 species of plants, including soybeans, other cultivated legumes such as peas and beans, and wild hosts including kudzu, which is widespread in the United States (Office of Technology Assessment; APHIS 2004a, 2004b).

P. pachyrhizi spores have the potential to disperse naturally over long distances and, under suitable climatic conditions, rapidly infect large production regions. Recent introductions of the pathogen into Uganda in 1996, Kenya, Nigeria, Rwanda, Zambia, and Zimbabwe in 1998, South Africa, Paraguay, and Brazil in 2001, northern Argentina in 2002, and Bolivia in 2004 have led to heightened concerns regarding the threat this pest poses to U.S. agriculture (Caldwell and Laing; Levy; Yorinori et al.; Rossi). As a result, USDA established a soybean rust surveillance, information, and education program to enhance the ability of domestic producers to respond effectively to rust establishment (APHIS, 2004a).

The extent of economic impacts will depend on the timing, location, spread, and severity of rust establishment and outbreaks, and on how soybean and crop producers, livestock producers, and consumers of agricultural commodities respond. In addition, the threat or actual arrival of a new pest of a major U.S. crop has implications for numerous public policies, including those concerned with invasive species, agricultural trade, pest control research, commodity programs, extension, pesticide regulation, and crop insurance.

Study Objectives

Periodic soybean rust outbreaks in the United States would likely induce a series of adaptations by agricultural producers, especially soybean growers, including changing production practices (e.g., using fungicides and, for some, altering their crop mix). Because some regions are projected to be more susceptible to rust establishment than others, impacts will likely vary considerably by region. While producers have limited management options during the first year of a rust outbreak, over time, as producers gain new information (e.g., rust spread advisories) and/or as new technologies (e.g., more efficacious fungicides or resistant varieties) become available, management options may increase.

The objective of this study is to examine potential economic implications of soybean rust establishment in the United States as a way of informing Federal research, extension, pest management, crop insurance and other programs that could be influenced by the expectation and/or realization of wind-borne natural establishment of this plant disease. The analysis was designed to account for:

- the likelihood of *P. pachyrhizi* spores from South America naturally reaching U.S. production regions;

- uncertainties surrounding yield and production cost impacts upon arrival in the United States;
- varying regional susceptibilities to rust establishment;
- commodity price changes; and
- economic adjustments of soybean and crop producers, livestock producers, and consumers of agricultural commodities.

Ranges for potential economic impacts are presented because uncertainties exist regarding the future arrival of *P. pachyrhizi*, variation in the suitability of regional climates for the establishment and severity of rust outbreaks, potential yield and production cost impacts, and producer responses. The study examines potential impacts for two time periods: (1) during the first year *P. pachyrhizi* is assumed to arrive in the United States (by wind after soybean planting), and (2) 3 years after it arrives, by which time it will have become permanently established in the southern United States. During the 3-year period after establishment, crop producers are assumed to have responded to soybean rust by adjusting the mix of crops they plant. Potential implications for selected USDA programs are also examined.

Background

The spread of soybean rust in the Western Hemisphere and the value of soybean production and utilization in the United States form the backdrop for current concern and policies promoting U.S. preparedness.

Asian Soybean Rust in South America

Although there are important differences between the United States and Brazil, the experience of the world's second-largest soybean producer with soybean rust can inform expectations about the likely impact on U.S. soybean production. (Outbreaks have also occurred in Paraguay, Bolivia, and northern Argentina.) Most of Brazil's soybeans are produced in frost-free zones, where vegetation lives year-round, multiple crops are possible, and climatic and ecological conditions are optimal for the introduction and dispersal of *P. pachyrhizi*: high humidity, temperatures between 55º and 80ºF, and long periods of leaf wetness. In the Center-West, a major producing region of Brazil, precipitation during the soybean-growing season averages 5 to 8 inches per month. The favorable climate has allowed *P. pachyrhizi* to spread rapidly since it was first introduced into Brazil in 2001. A year later, infestations were found in approximately 60 percent of the country's soybean area. Losses from soybean rust during 2001/2002 were estimated by Brazil's agricultural research agency, EMBRAPA, at 570,000 metric tons—about 1 percent of Brazilian production (Yorinori et al.).

In 2002/03, a particularly wet season helped spread the fungus so that soybean rust was present in 95 percent of Brazil's soybean-producing areas. Losses increased to an estimated 3.4 million tons, or about 6 percent of total production, although the damage was concentrated in two States: Mato Grosso (2.4 million tons) and Bahia (0.7 million tons). Damage was limited for the later sown crops of other States because growers in these areas were better informed about the risks of soybean rust and applied fungicides in a timely manner. Hot temperatures during 2003 were also thought to have moderated the disease's spread in southern Brazil (Yorinori et al.).

About 80 percent of Brazil's soybean area received an average of two fungicide sprays in 2002/03 at a cost of nearly $600 million (Yorinori et al.). Depending on the situation, EMBRAPA recommends that growers choose from among 11 different commercial fungicides to control soybean rust. All of them are classed as either strobilurins or triazoles, which are fungicides widely used in Brazil on soybeans as well as on other crops. In Mato Grosso, producers generally applied a minimum of two fungicide treatments at a cost of about $50 per hectare. This raised total soybean production costs from pre-rust levels by an estimated 15 percent (Reuters). The widespread use of fungicides prevented production losses from falling more than about 6 percent from estimated rust-free levels.

In general, Brazilian producers have quickly adapted to this new pest with modest increases in production costs and relatively small country-wide yield declines. Despite the adverse impacts on yields, costs, and management requirements from soybean rust, there are few field crops that can be raised in Brazil as profitably as soybeans.

Characteristics of the U.S. Soybean Sector

U.S. farmers planted 73.4 million acres of soybeans in 2003. With the U.S. farm value of the 2003 soybean crop likely to exceed $18 billion, it ranks behind only corn in value. Although the aggregate export volume of soybeans, soybean meal, and soybean oil typically amounts to less than half of the U.S. soybeans produced each year, exports from the soybean sector exceeded $8 billion in fiscal 2003, which was 15 percent of all U.S. agricultural exports (*Outlook for U.S. Agricultural Trade*).

The U.S. livestock sector is vulnerable to soybean production shocks because various forms of soybeans are used in and as livestock feed. In the United States, livestock feeds account for 98 percent of all soybean meal consumed, with a relatively small amount used in human foods. While grains account for most feed concentrates consumed by domestic livestock, soybean meal use exceeds 30 million tons, or approximately 14 percent of all concentrates fed (United Soybean Board). Estimates from the United Soybean Board indicate that about 44 percent of domestic soybean meal use is currently consumed by poultry, 24 percent by hogs, and 19 percent by dairy and beef cattle, with the remainder used by other animals.

Within the United States, soybean acreage has gradually become more concentrated in the Midwest since the early 1980's and less prominent in the South. Southern States accounted for 16 percent of U.S. soybean acreage between 1998 and 2002, compared with 36 percent between 1980 and 1984. Part of the reason for the decline is that soybean yields in the South rose more slowly than the national average, slipping from 7 bushels below in 1980-84 to 11 bushels below in 1998-2002. Production costs per acre are also generally higher in the South, so with lower yields, net returns for soybeans are significantly lower. Based on assumptions of where an introduction of soybean rust is most likely to become established (i.e., in relatively warm, humid climates), this production geography has a bearing on the national economic impact of rust establishment.

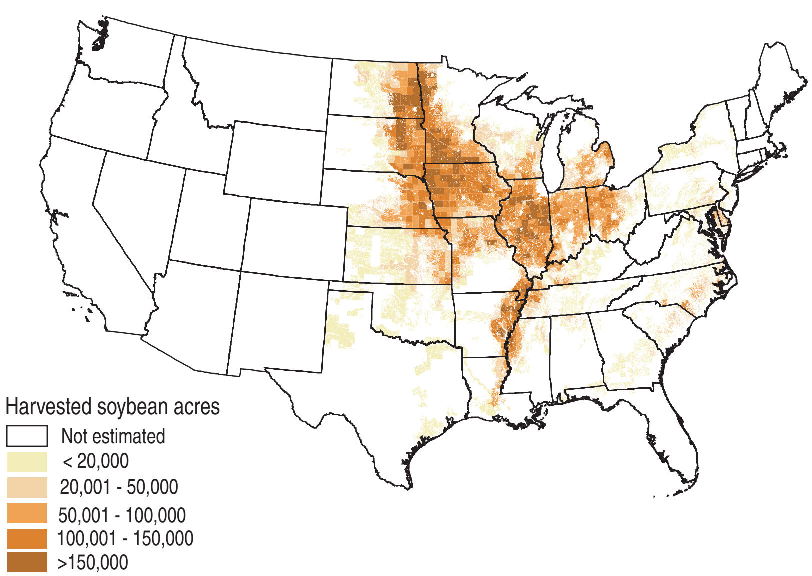
In the past, the United States was the world's primary soybean producer and the decision to expand output following a U.S. crop failure depended on the planting decisions of domestic producers. Now, acreage gains following U.S. production losses are more muted because South American producers can respond to a U.S. shortfall. In the late 1970's, approximately two-thirds of global soybean production came from the United States compared with 38 percent in 2002/03. Strong expansion of South American soybean production in recent years has eroded U.S. producers' dominant position and has affected global prices.

Differences between South American and U.S. Vulnerabilities to Soybean Rust Outbreaks

U.S. soybean production is concentrated along the Mississippi River and in the Corn Belt and Northern Plains (National Agricultural Statistics Service) (figure 1). In contrast to Brazil, most U.S. soybeans are produced within the 35-45 degree north latitudes, where there are lengthy periods of below freezing temperatures. The U.S. Corn Belt averages about 3.5-4.5 inches of precipitation per month during the growing season.

An analysis of temperature, relative humidity, and rainfall data from more than 2,000 soybean production areas around the world suggests that soybean production areas can be divided into two distinct categories: those where soybean rust can survive year-round in the presence of suitable hosts; and those where occurrences of rust outbreaks depend on long-distance spore dispersal (Pivonia and Yang). Regions in the former category include China south of 37ºN, eastern Australia, Indonesia, Africa, Brazil, and Paraguay, as well as regions where soybean rust is not yet present, including northern South America, Central America, Mexico, the Caribbean, and the southern

Figure 1
Harvested soybean acres by county, 2003



Source: USDA-NASS

United States. Regions in the latter category include China north of 37ºN, and the northern U.S. soybean-producing areas. Pivonia and Yang's results suggest the occurrence of U.S. rust outbreaks will likely vary much more than in Brazil, where environments are more hospitable to the year-round survival of the pathogen.

Finally, U.S. soybean producers have greater inherent flexibility than Brazilian soybean growers. The choice of crops in Brazil's Center-West is particularly inflexible because of the lack of profitable alternatives to soybeans and limited credit financing for crops other than soybeans. In Mato Grosso, soybean yields are among the highest in the world (recently averaging 45-46 bushels per acre), but corn yields are comparatively low and more variable. Obtaining credit is also a chronic problem in Brazil. Expansion of new farmlands and financing of crop planting in that region can be easily obtained for soybeans, which has an established foreign market. However, capital is less available for crops like corn or cotton whose export markets in Brazil are less developed. In the United States, on the other hand, soybean producers in nearly all production regions can grow alternative crops and readily secure credit, if necessary.

Public Policy Implications of Soybean Rust

A number of public policies or programs may be affected by the introduction of soybean rust into the United States including:

- *Crop insurance programs*—The Federal crop insurance program is designed to reduce production risk and serves as a "safety net" for producers who have opted to participate. Producers have several programs and coverage levels to choose from, and insurance is structured so that producers bear some portion of the yield and/or price risk. If soybean yields decline sufficiently due to soybean rust outbreaks (or other natural perils), covered producers receive compensation to the extent of their insured losses. Over time, premium rates would adjust to reflect chronic, periodic outbreaks of soybean rust.
- *Farm programs*—Under current farm programs, a disease-related rise in the market price could result in a decline in the marketing loan benefits for producers (which are available on all production), provided that market prices are below the loan rate when the supply shock occurs. These program benefits are expected to be near zero for the 2003 soybean crop but had been as high as $3.4 billion in crop year 2001. If the market price increase were large enough, counter-cyclical payments for soybeans (which were enacted in 2002) would also be reduced. Counter-cyclical payments are based on fixed program yields and base acreage, so only price changes (and not actual production) will affect such payments. A severe soybean rust infestation could increase the possibility of disaster payments to soybean producers similar to past drought assistance programs.
- *Research and Extension programs*—The potential for soybean rust establishment in the United States has generated demand for research to determine efficacious fungicides, predict epidemics, and evaluate fungicide application methods. Related research will be necessary for identifying and predicting the factors affecting spore production, dispersal,

and deposition if soybean rust becomes established in the United States (i.e., early warning models to assist producers in making treatment decisions). Additional programs may be needed to communicate information specific to controlling soybean rust to producers through the Cooperative Extension system. A major outbreak of soybean rust would likely induce new public research funding for soybean rust management alternatives. While the private sector, particularly the pesticide and seed industries, would likely respond with new fungicide products and resistant varieties, the public sector could help develop these and other enhanced soybean rust management technologies and practices.

- *Risk mitigation programs*—The threat of soybean rust entering the United States has led to an assessment of the risks of introduction through potential anthropogenic pathways (i.e., trade and travel) (APHIS, 2004b). Such an assessment will help inform any regulatory decisions needed to assure that those risks remain at acceptable levels. Economic analysis can help to determine the levels of resources necessary for monitoring soybean rust and evaluating the potential success of any quarantine activity (APHIS, 2004a).
- *Pesticide regulatory programs*—Given that only a small number of fungicides are currently registered for use against soybean rust on soybeans in the United States, the threat of infestation has prompted several States to request a quarantine exemption from EPA for several new fungicides (Sierk et al.). However, some fungicides, such as the triazoles, which are targeted to control soybean rust, may pose environmental and/or food safety risks. The potential for a large number of soybean acres to be treated with such fungicides may trigger a reassessment of aggregate environmental and/or food safety risks vis-a-vis production benefits.
- *Food aid programs*—Lower supplies of soybeans, soybean meal, and soybean oil could affect the availability and costs of these commodities for U.S. food aid programs. The main food aid programs are Public Law 480, Section 416 (b), Food for Education, and Food for Progress. In fiscal year 2003, U.S. Government acquisitions by those four programs included: 10,000 tons of soybeans valued at $2.3 million; 135,600 tons of soybean meal valued at $29.1 million; and 317,600 tons of vegetable oil (principally soybean oil) valued at $258 million. In recent years, a negligible amount of soybean stocks defaulted to the CCC, so supplies for food aid must now be purchased at prevailing market rates.

Assumptions of the Analysis

The economic analysis of a potential soybean rust establishment and subsequent periodic outbreaks is based on a number of underlying assumptions, and these assumptions differ depending on whether a first-year impact (assumed to be 2005) or medium-term impact (3-years after the initial establishment or 2008) is examined (table 1). The first-year and medium-term economic impacts are estimated relative to the 2005 and 2008 projections in the 2001 USDA baseline. To examine expected impacts of first-year soybean rust establishment in a specific U.S. soybean-producing region (or multiple regions), the analysis incorporates climatic transport probabilities from South America, the probability of spore survival in a given region, the expected yield loss associated with rust establishment, and the cost of fungicide applications. Incorporating regional probabilities of the arrival of soybean rust spores allows the economic impacts to be presented in terms of expected losses (i.e., the sum, across all scenarios, of the probability of a scenario times the estimated impact of the scenario). In addition, during the first-year of soybean rust establishment, producers in the affected region(s)

Setting the Scene for Economic Analysis of Wind-Borne Entry and Establishment of Soybean Rust in the U.S.

The initial establishment of soybean rust in the United States is likely to have consequences that differ from subsequent outbreaks that may recur annually after establishment. We therefore analyze economic implications for two different time-horizons: an initial outbreak and 3 years after the initial outbreak.

Initial Soybean Rust Establishment

Although no one knows when or if an initial soybean rust outbreak will occur in the United States, we derived probabilities of different establishment scenarios using information based on research by aerobiologist Scott Isard of the University of Illinois. These probabilities quantify the likelihood an initial outbreak will occur in a given production region. Air currents could disperse soybean rust spores over a single soybean-producing area, or over several locations, or throughout the entire U.S. The resultant probability distribution allows us to estimate an ***expected value*** of economic impacts for the assumed initial year of soybean rust entry (i.e., 2005). We calculate this expected value for two yield change assumptions stemming from soybean rust outbreaks (i.e., -9.5 and +0.9 percent yield changes).

Mathematically, the expected value multiplies the probability that each establishment scenario will occur by the aggregate economic impact of that scenario and then sums these over all possible geographical extents of the initial outbreak. (Sixty-four possible geographical extents of the initial outbreak were considered.) We denote different geographical extents using the subscript i, the probability of an initial outbreak event by P_i, and an economic impact measure for the outbreak event by I_i. Using this notation,

expected economic impact $= P_1 I_1 + P_2 I_2 + P_3 I_3 + \ldots + P_{64} I_{64}$

Subsequent Years:
The Case of Periodic Soybean Rust Outbreaks

Permanent, over-wintering of soybean rust is likely only in the Southeastern United States. Once established, we assume some level of periodic outbreak could occur in any year subsequent to the initial year of establishment. The impact for any given year will depend on the extent of the annual periodic outbreak—how far North and/or West it extends—which depends primarily on the weather. We use a climate suitability index (based on historical weather patterns) to calibrate the severity of recurring future impacts across regions.

are assumed to be able to treat with fungicides to prevent some or most of the potential yield loss, but unable to shift to alternative crops.

In the medium term (by 2008, i.e., 3 years after the assumed initial entry of soybean rust), soybean rust is assumed to be established in the United States, but no information about the probabilities of soybean rust outbreaks in specific regions or neighboring regions (i.e., joint probabilities of spread from soybean-rust-endemic regions to non-endemic regions) is currently available. We know, however, that the susceptibility of regions to annual periodic outbreaks varies according to climatic characteristics. Thus, selected geographic scenarios of rust outbreak extent are analyzed, and yield loss and fungicide cost estimates are adjusted by regional climate suitability indices. Producers are shown to adapt to likely soybean yield losses and soybean fungicide cost increases by shifting to more profitable crops where possible. Economic impacts on agricultural producers and consumers in the medium term are based on the relative propensities for various regions to experience annual soybean rust outbreaks and to adjust to changes in regional comparative advantage in producing soybeans versus other crops.

Table 1—Assumptions underlying the impact analyses of first-year establishment and medium-term outbreaks of soybean rust

Assumptions	First-year impacts	Medium-term impacts
Economic model	USMP	USMP
Baseline year[a]	2005	2008
Market adjustments simulated	Prices and livestock production	Prices, cropping decisions, livestock production
Fungicide cost ($/acre)	$25	$25
Yield impacts	-9.5%; +0.9%	-9.5%; -4.3%; +0.9%
Probabilities of rust establishment	Regional soybean rust spore arrival and survival	Not applicable
Regional susceptibility to post-establishment soybean rust outbreaks	Not applicable	Regional climate suitability factor
Regional extent scenarios[b]	AP AP+CB AP+CB+SE AP+CB+SE+DL AP+CB+SE+DL+NP AP+CB+SE+DL+NP+LS	AP+DL+SE AP+DL+SE+CB+NE AP+DL+SE+CB+NE +LS+NP+SP

[a]Source: USDA (2001).
[b]NE (Northeast) = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; LS (Lake) = MI, MN, WI;
CB (Corn Belt) = IA, IL, IN, MO, OH;
NP (Northern Plains) = KS, ND, NE, SD; AP (Appalachia) = KY, NC, TN, VA, WV;
SE (Southeast) = AL, FL, GA, SC;
DL (Delta) = AR, LA, MS; SP (Southern Plains) = OK, TX.

Estimating Yield and Cost Impacts

Assumptions about potential yield and production cost impacts of rust establishment are critical to the analysis. Since no data on potential yield losses for the United States are available, the analysis considers a range of yield losses based on estimates of rust-free and treated yields in Brazil and Paraguay during 2001–2003 (BASF; Bayer 2003a, 2003b; Sierk et al.). These data suggest that treated soybean yields average 4.3 percent lower than estimated, rust-free yields, but with a range between 9.5 percent lower to 0.9 percent higher than rust-free yields. Consequently, we examine the economic consequences of the following yield impacts: -9.5 percent, -4.3 percent and +0.9 percent.[1]

The yield increase possibility arises from the fact that fungicides used to manage rust outbreaks, especially for a relatively mild rust infestation, also manage other diseases (e.g., anthracnose, stem canker, Diaporthe pod and stem blight, frogeye leaf spot, Cercospora blight, purple seed stain, and Septoria brown spot), which may reduce yield but are not profitable to manage individually (Hartman et al.). Also, some fungicides may have a direct, yield-enhancing impact (Miles; Smith).

Information on the likely cost of fungicide treatments was partially drawn from data submitted to the EPA in a request for a quarantine exemption for fungicides to treat soybean rust (Sierk et al.).[2] Fungicide material and application (ground and air) costs are assumed to average roughly $19 per acre, but exhibit considerable variation depending on the type of fungicide and number of treatments.[3] A test of the analytical model's sensitivity to assumptions about fungicide treatment costs showed that economic outcomes are relatively insensitive to the cost of treatment compared to yield changes. This analysis assumed a higher figure of $25 per acre,[4] assuring some conservatism in the analytical assumptions with the knowledge that overall outcomes were not unduly affected.

The Economic Model

Potential impacts of soybean rust establishment and subsequent outbreaks in the United States are simulated using a spatial equilibrium, mathematical-programming model (USMP) of the U.S. agriculture sector.[5] USMP includes 45 geographic sub-regions based on the intersection of 10 USDA Farm Production Regions and 25 USDA Land Resource Regions. Twenty-three inputs are included, as are the production and consumption of 44 agricultural commodities and processed products. The model accounts for more than 5,000 crop production enterprises at the sub-regional level—according to cropping rotations, tillage practices, and fertilizer rates—and more than 90 livestock and poultry production enterprises at the regional level by species. Agricultural markets for inputs such as land (crop and pasture), labor (family and hired), and irrigation water are specified at the regional level, and the demand for roughly 23 other inputs (e.g., fertilizer and seed) is subject to fixed, national prices. Nearly 1,000 primary commodity and 70 processing activities (e.g., producer input demand) and consumer demand activities in 44 competitive crop, livestock, and processed product markets are chosen to maximize net returns to all agricultural producers and consumers, subject to market-clearing constraints.

[1]From a historical perspective, a 9.5-percent yield decline is not unprecedented in the United States. During the last 12 years, droughts caused year-over-year national soybean yield declines in both 1993 and 2003 of over 13 percent.

[2]While quarantine or emergency exemptions are typically not granted for a pest not present in the U.S., EPA has adopted a proactive policy in the case of soybean rust and has granted several exemptions conditioned on the confirmation by USDA that soybean rust is present in the continental U.S. (March 25, 2004, EPA letter to Minnesota and South Dakota Departments of Agriculture).

[3]Representative products available, or likely to become available, to treat soybean rust in the United States include: (1) such triazole products as propiconazole, tebuconazole, myclobutanil, and tetraconazole; and (2) such strobilurin-based products as azoxystrobin, propiconazole + trifloxystrobin, pyraclostrobin, and pyraclostrobin + boscalid (Sierk et al.).

[4]Based on an average yield of 35 bu/acre and a soybean price of $6/bu (i.e., about the average yield and price during the 1990's), and assuming that untreated yield losses would be more than 25 percent, producers would likely find it profitable to spend at least $25/acre on fungicides to reduce losses to below the maximum yield loss assumed in this analysis (i.e., 9.5 percent).

[5]This model of the U.S. agriculture sector has been used to examine economic and environmental consequences associated with water quality (Ribaudo et al.) and wetlands (Claassen et al.) policies, sustainable agriculture (Faeth), and climate-change mitigation (Peters et al.). USMP accounts for production of the major crop (corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, hay, silage) and livestock enterprises (beef, dairy, swine, and poultry) comprising approximately 75 percent of agronomic production and more than 90 percent of livestock production (NASS, 1997).

USMP simulates likely adjustments made by crop, feed, and livestock producers and consumers after soybean rust is introduced into the United States. More specifically, USMP simulates the impacts of reduced soybean yields and increased production costs (i.e., fungicide treatments) for a number of scenarios exploring different geographic assumptions about potential soybean rust establishment.

Summarizing the economic impacts of yield and cost shocks to U.S. agricultural producers and consumers requires examining a number of economic indicators. For this analysis, changes in five economic indicators are presented: soybean producer net returns (market returns less variable and fixed costs except land), other crop producer net returns, livestock producer net returns, net consumer impacts (consumer benefits minus consumption expenditures), and aggregate societal impacts (the sum of producer and consumer impacts). Underlying these economic impacts are changes in prices, costs, and production of the major agricultural commodities under the various soybean rust outbreak scenarios examined.

The agricultural sector simulation model was not designed to examine transition paths between initial and subsequent agricultural market equilibria. Thus, the study assumed that an initial infestation occurs during 2005 and, for the scenarios in which crop producers were allowed to adjust to soybean rust outbreaks, that the new equilibrium occurs in 2008. Reported impacts are relative to 2005 and 2008 projections reported in, or consistent with, the 2001 USDA baseline. Monetary values are discounted to 2004 U.S. dollars.

First-Year Soybean Rust Establishment

The first-year analysis of potential soybean rust establishment in the United States is based on an assessment of the chances (probabilities) that various different geographic extent-of-establishment scenarios will occur, the costs of fungicides, and a range of possible soybean yield impacts. The probabilities of various extent-of-establishment scenarios are based on a natural (windborne) infestation from South America. The estimated impacts assume that crop plantings cannot be adjusted in the first year but livestock utilization and all agricultural prices can and will adjust in the short run.

Probabilities of Initial Soybean Rust Establishment

This analysis assumes rust establishment, if it does occur in the United States, will be caused by spores arriving from South America, since spore dispersal over longer distances appears to be extremely rare (Brown and Hovmøller). Based on biological and meteorological research, Isard estimated relative risk indices of soybean rust establishment in various regions of the United States. These risk indices pertain to the relative likelihood that spores will be introduced into different regions of the United States during different time periods. From these relative risk indices, conditional probabilities of establishment for combinations of regions were derived based on individual regional probabilities.

Expected First-Year Impacts

Table 2 summarizes the estimated, expected, first-year economic impacts associated with soybean rust-induced yield losses and production cost increases to soybean producers who are assumed to have sufficient advance warning to make fungicide treatments. Conditional on an infestation's actually occurring, aggregate expected net social losses (i.e., reduction in producer plus consumer surplus) range from $640 million to $1,341 million depending on the severity of the assumed effect on yield (+0.9 percent to -9.5 percent). In the yield loss case, the $1,341 million expected loss to society appears large in an absolute sense, but it represents less than 1 percent of the net benefits (i.e., consumer plus producer surplus) generated by the agricultural sector. The small relative impact of rust establishment is an indication of the resilience of the agricultural sector to withstand unanticipated shocks. Expected losses are much smaller in the yield increase scenario because soybean production actually increases, benefiting other sectors of the economy, especially consumers.

When yield losses of 9.5 percent are incurred, much of the expected first-year economic losses (where planted acreage is fixed) are borne by soybean producers due to increased fungicide expenses and reduced yields. In this scenario, soybean producers incur expected losses of about $1 billion or 75 percent of the aggregate societal losses of $1,341 million. Consumers bear only $271 million (20 percent) of overall expected losses. The livestock sector also incurs losses due to soybean meal price increases, producing net return losses for that sector as well.

A slightly different result emerges from the first-year scenario where soybean yields increase, leading to price declines for soybeans and related feedstocks. Soybean producers bear all the losses in this scenario ($674 million) reflecting higher fungicide expenditures, but the losses are smaller than in the yield loss scenario since increased production offsets the slightly lower soybean price. On the other hand, soybean consumers and the livestock sector benefit from lower soybean and soybean meal prices.

Table 2—First-year expected economic impacts of soybean rust establishment[a]

	Soybean producers	Livestock producers	Other crops producers	Consumers	Total net change[c]
2005 baseline ($million)[b]	5,038	36,100	24,086	408,149	468,335
Yield Impact of -9.5%					
Expected value ($million)	-1,004	-52	-14	-271	-1,341
Percent change from baseline	-19.93	-0.14	-0.07	-0.07	-0.29
Yield Impact of +0.9%					
Expected value ($million)	-674	6	1	27	-640
Percent change from baseline	-13.37	0.02	0.00	0.01	-0.14

[a]These are conditional expected values, or expectations given a rust epidemic occurs in the United States.
[b]Economic impacts are compared to 2005 levels derived from baseline projections (USDA 2001).
[c]Total net change is the sum of changes experienced by all crop producers, all livestock producers, and all consumers of affected commodities.

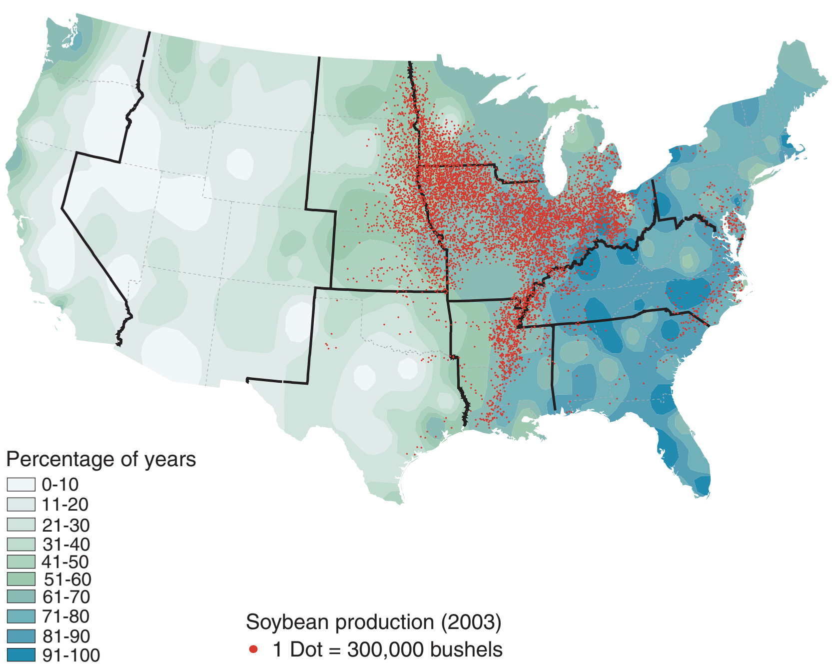
Medium-Run Impacts of Soybean Rust Outbreaks

Data on how soybean rust will periodically spread across the major U.S. soybean production regions (if and when soybean rust becomes endemic in the southern United States) are not available. It is assumed that the periodic rust outbreaks would originate from reservoirs among host species, such as kudzu, in the South or from regions near the Gulf of Mexico. To simulate medium-run scenarios of soybean rust outbreaks, once the fungus is endemic to the United States, aggregated indices of environmental suitability were developed for eight soybean-producing regions based on estimates by Magarey (figure 2). Magarey used an infection model in the NAPPFAST predictive system (Anon., 2004) to determine the suitability of the climate for infection by *P. pachyrhizi.*

The infection model is based upon a temperature response function (Wang and Engel, 1998), scaled to the minimum wetness duration requirement. The model parameters are the cardinal temperatures (T) and the minimum and optimum wetness (W) duration requirement. For *P. pachyrhizi*, these were estimated to be Tmin = 10°C, Tmax = 28°C, Topt = 23°C, Wmin = 8 hours and Wopt = 12 hours. At least 15 such days are required for the development of a serious epidemic. Using 30 years of daily temperature and leaf wetness data, Magarey estimated the infection potential for each 10-square-kilometer area in the continental United States. Magarey's infection potential map was converted into a regional soybean rust suitability index (table 3) to reflect regional propensities to host soybean rust based on historic weather data.

Figure 2

Percentage of years out of 30 that climatic conditions are expected to support outbreaks of soybean rust



Source: Magarey 2003

Medium-Run Impacts after Adjustment

Because there are no data to generate probabilities of soybean rust spread once it has become established in the United States, several scenarios are simulated to provide ranges for medium-run impacts of soybean rust outbreaks. These scenarios consider varying geographic extent and yield loss assumptions but assume fungicide costs are fixed. Results are presented for three of these scenarios: a "Low Spread" scenario with limited geographic infestation (in the Appalachia, Southeast, and Delta regions), a yield increase of 0.9 percent on treated acres, and $25-per-acre treatment cost; a "Medium Spread" scenario with moderate geographic infestation (in the Appalachia, Southeast, Delta, Corn Belt, and Northeast regions), a 4.3-percent yield decrease on infected acres, and a $25-per-acre treatment cost; and a "High Spread" scenario with extensive geographic infestation (in all soybean production regions), a 9.5-percent yield decrease on infected acres, and a $25-per-acre treatment cost. Medium-run impacts are summarized in tables 3-6.

To incorporate data on the relative propensity of regions to host soybean rust, yield shocks and fungicide treatment costs were assumed to affect that portion of the regional soybean acres reflected by the regional suitability indices shown in the first row of table 3. For example, the 9.5-percent yield loss shock and $25-per-acre fungicide cost is applied to 70 percent of the Corn Belt acres, as a way of representing the relative propensities for rust-related economic impacts. Consequently, the study assumes that different rust-affected regions will have different geographic and yield loss shocks based on the assumed suitability for soybean rust (see box).

Once soybean rust becomes established in the United States, producers are assumed to adjust their crop mix in response to the likelihood of periodic soybean rust outbreaks. In the years following the arrival of soybean rust, producers would be faced with the prospect of lower soybean yields and increased production costs in regions subject to outbreaks. In regions prone

Table 3—Baseline soybean acres, soybean rust suitability index, and medium-term percent changes in soybean acres by region

Regions	NE	LS	CB	NP	AP	SE	DL	SP	US
Regional suitability index	0.76	0.59	0.70	0.54	0.78	0.83	0.66	0.38	na
Baseline soybean acres (million)	1.1	8.6	37.6	8.5	5.5	3.3	9.4	0.3	74.2[a]
Scenario:[b]			*Percent change in soybean acres, 2008*						
High Spread	-7.4	-5.8	-2.0	-6.9	-12.4	-14.9	-10.5	-1.0	-5.5
Medium Spread	-6.6	2.3	-1.9	2.1	-11.3	-13.3	-10.0	1.2	-3.2
Low Spread	0.4	0.5	0.2	0.5	-9.4	-8.7	-8.6	0.3	-1.9

[a]Soybean acres are compared to 2008 levels derived from baseline projections (USDA 2001).
[b]High Spread = All Soybean Regions; -9.5% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index;
Medium Spread = AP, SE, DL, CB, and NE Regions; -4.3% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; and
Low Spread = AP, SE, and DL Regions; positive 0.9% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; where
NE (Northeast) = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; LS (Lake) = MI, MN, WI; CB (Corn Belt) = IA, IL, IN, MO, OH;
NP (Northern Plains) = KS, ND, NE, SD; AP (Appalachia) = KY, NC, TN, VA, WV; SE (Southeast) = AL, FL, GA, SC;
DL (Delta) = AR, LA, MS; SP (Southern Plains) = OK, TX; US (United States).

to experience annual soybean rust outbreaks, producers would examine alternative uses of their cropland, and if soybean production appeared relatively less profitable, they would choose to plant alternative crops. The analysis indicates that across the different scenarios, acreage planted to soybeans falls from between 1.9 percent and 5.5 percent (table 3).

Because producers in different regions have different cropping alternatives, the impacts of rust outbreaks are not evenly distributed across all soybean-growing areas. For regions in which rust is less likely to occur, soybean producers will benefit from higher soybean prices and therefore will plant more acres to soybeans. Consider the "Low Spread" scenario, where a soybean rust outbreak occurs in the Appalachia, Delta, and Southeast regions. Crop producers in infested regions reduce acres planted to soybeans and shift to alternative crops; in the Delta region, much of the soybean acreage shifts into corn, sorghum, rice, and cotton. Conversely, in all other regions soybean acres increase as producers respond to higher soybean prices and net returns relative to other cropping opportunities.

With fewer soybean acres, in aggregate, production falls and soybean prices rise (table 6). Soybean producers under a severe infestation (all regions and large yield shock) would be expected to see a 21-percent decrease in returns to production (table 4), in aggregate. Returns to soybean production fall by nearly 3 percent even when yields increase (under a "Low Spread" case) due to increased production costs associated with fungicide treatments. Higher soybean prices lead to increased feed costs and lower livestock and poultry sector profits. Returns to livestock and poultry production are expected to fall, but by less than 0.5 percent across the three scenarios. On

Table 4—Medium-term economic impacts of soybean rust outbreaks, as changes from baseline projections

	U.S. agriculture				
	Soybean producers	Livestock producers	Other crop producers	Consumers	Total net change[a]
2008 baseline ($million)[b]	5,776	33,000	18,904	340,233	397,913
Scenarios[c]					
High Spread ($million)	-1,213	-137	22	-675	-2,004
Percent change from baseline	-21.01	-0.41	0.11	-0.20	-0.50
Medium Spread ($million)	-828	-57	5	-287	-1,168
Percent change from baseline	-14.34	-0.17	0.03	-0.08	-0.29
Low Spread ($million)	-164	-9	18	-84	-240
Percent change from baseline	-2.84	-0.03	0.09	-0.02	-0.06

[a]Total net change is the sum of changes experienced by all crop producers, all livestock producers, and all consumers of affected commodities.
[b]Economic impacts are compared to 2008 levels derived from baseline projections (USDA, 2001).
[c]High Spread = All Soybean Regions; -9.5% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index;
Medium Spread = AP, SE, DL, CB, and NE Regions; -4.3% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; and
Low Spread = AP, SE, and DL Regions; positive 0.9% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; where
NE (Northeast) = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; LS (Lake) = MI, MN, WI; CB (Corn Belt) = IA, IL, IN, MO, OH;
NP (Northern Plains) = KS, ND, NE, SD; AP (Appalachia) = KY, NC, TN, VA, WV; SE (Southeast) = AL, FL, GA, SC;
DL (Delta) = AR, LA, MS; SP (Southern Plains) = OK, TX.

the other hand, net returns increase for other crops as producers shift from soybeans to alternative crops, mainly corn, sorghum, rice, and cotton. Many of these producers also grow soybeans and can offset reduced soybean net returns by producing other crops. Other crop producers gain marginally, by less than 0.5 percent under the range of scenarios considered. Overall, total net producer plus consumer effects under these scenarios drop only 0.5 to 0.06 percent from the base.

The regional distribution of estimated, medium-run impacts on producers of soybeans and other agricultural commodities are shown in table 5. As expected, the geographic extent and severity of periodic soybean rust outbreaks drive the changes in returns to soybean production. When soybean rust is assumed to infest a given region, soybean acres and soybean net returns decline (table 3 and table 5). Livestock producers in all regions,

Table 5—Medium-term changes in returns to producers by region, as changes from baseline projections

Regional returns	Scenario[a]	NE	LS	CB	NP	AP	SE	DL	SP	M	P
						Million dollars					
Soybean producers	High Spread	-20	-94	-677	-88	-107	-63	-163	-1	0	0
	Medium Spread	-18	51	-609	55	-95	-58	-156	2	0	0
	Low Spread	2	12	68	13	-75	-50	-135	0	0	0
Livestock producers	High Spread	-8	-5	-13	-15	-24	-26	-21	-16	-5	-4
	Medium Spread	-3	-2	-5	-6	-10	-11	-9	-6	-2	-2
	Low Spread	0	0	-1	-1	-2	-2	-2	-1	0	0
Other crop producers	High Spread	4	-12	-20	9	7	11	35	-7	-4	-3
	Medium Spread	3	3	-37	-4	5	10	33	-4	-2	-1
	Low Spread	-1	-1	-9	-3	4	7	27	-4	-2	0

[a]High Spread = All Soybean Regions; -9.5% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; Medium Spread = AP, SE, DL, CB, and NE Regions; -4.3% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; and Low Spread = AP, SE, and DL Regions; positive 0.9% yield shock and $25/acre treatment on a portion of the regional acreage that reflects the regional suitability index; where NE (Northeast) = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; LS (Lake) = MI, MN, WI; CB (Corn Belt) = IA, IL, IN, MO, OH; NP (Northern Plains) = KS, ND, NE, SD; AP (Appalachia) = KY, NC, TN, VA, WV; SE (Southeast) = AL, FL, GA, SC; DL (Delta) = AR, LA, MS; SP (Southern Plains) = OK, TX; M (Mountain) = AZ, CO, ID, MT, NM, NV, UT, WY; P (Pacific) = CA, OR, WA.

Table 6—Medium-term economic impacts on the soybean sector, as changes from baseline projections

	Additional fungicide costs ($million)	Price[a] ($ per bu)	Production (million bu)	Exports (million bu)	Acres (million)	Net returns ($million)
2008 baseline[b]	0.00	4.99	3,150	1,055	74.2	5,776
			- - - - - - - - - - *Percent change* - - - - - - - - - -			
Scenario[c]						
High Spread	$961	+6.02%	-10.2%	-5.6%	-5.5%	-21.01%
Medium Spread	$779	+2.76%	-4.7%	-2.6%	-3.2%	-14.34%
Low Spread	$246	+0.65%	-1.1%	-0.6%	-1.9%	-2.84%

[a]Discounted to 2004 dollars.

[b]Economic impacts are compared to 2008 levels derived from baseline projections (USDA 2001).

[c]High Spread = All Soybean Regions; -9.5% yield shock and $25/ac treatment on a portion of the regional acreage that reflects the regional suitability index; Medium Spread = AP, SE, DL, CB, and NE Regions; -4.3% yield shock and $25/ac treatment on a portion of the regional acreage that reflects the regional suitability index; and Low Spread = AP, SE, and DL Regions; positive 0.9% yield shock and $25/ac treatment on a portion of the regional acreage that reflects the regional suitability index; where NE (Northeast) = CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT; LS (Lake) = MI, MN, WI; CB (Corn Belt) = IA, IL, IN, MO, OH; NP (Northern Plains) = KS, ND, NE, SD; AP (Appalachia) = KY, NC, TN, VA, WV; SE (Southeast) = AL, FL, GA, SC; DL (Delta) = AR, LA, MS; SP (Southern Plains) = OK, TX.

and all scenarios, have declines in net returns due to higher soybean prices. In general, a decrease in regional returns to soybean production is followed by a shift to alternative crops and an increase in returns to the production of other crops. For the United States, as a whole, returns to other crops increase as acreage shifts out of soybeans. However, exceptions occur for certain regions and scenarios. For example, in the medium spread scenario for the Corn Belt, net losses to soybean production are accompanied by lower net returns for other crops. Producers in this region shift to crops that substitute for soybeans, but this results in lower overall net returns, reflecting reduced prices that arise from increased production. Note that even though there are very few soybeans produced in the Mountain and Pacific States, livestock producers in these regions are adversely affected by soybean rust outbreaks.

Soybean producers bear most (60-70 percent) of the costs of adjusting to soybean rust, while consumers and livestock producers shoulder the remainder of the economic burden. Consumers are adversely affected by higher livestock product prices as well as by higher prices for consumer products derived from soybeans, but losses are likely to be less than 0.5 percent of the consumers' baseline level.

Implications

The analysis has implications for a variety of public policies and programs.

Crop Insurance—The analysis indicates that, because the Southeast, Delta, and Appalachia States may be more prone to soybean rust than the Northern Plains and Lake States, changes in production risks could alter producer crop production decisions in these regions. Furthermore, while crop insurance rates for future years are normally based on the historical record of losses in past years, it may be reasonable to adjust rates in anticipation of the arrival of soybean rust in a region in order to avoid running a short-term deficit in the crop insurance program.

Disaster Assistance—A widespread and severe loss of soybean production due to soybean rust may encourage legislation to assist growers who are not covered by crop insurance. There is a precedent for a special disaster program's being established to assist growers who suffer a yield loss due to disease. Disaster aid is typically paid only after crop insurance proceeds and any gross market returns are deducted from a historical per acre gross revenue ceiling.

Pest Management Research Programs—The analysis suggests that agricultural producers and consumers could benefit (i.e., economic loss prevented) by as much as $67 million for each 1 percent of soybean yield loss from soybean rust that could be avoided. This has implications for technological advances that may follow from investment in research and development on more tolerant soybean cultivars or more effective timing and application of efficacious fungicides to prevent or limit soybean rust outbreaks.

Pest Monitoring and Forecasting—The analysis suggests that the value of delaying entry of soybean rust by, for example, subsidizing control programs in South America or by precisely identifying and eliminating any highly isolated early outbreaks, may be worth between $640 and $1,341 million.[6]

Environmental Implications—The analysis examined the environmental implications of changes in acreage, regional cropping patterns, and input use associated with rust outbreaks. In particular, the quantity of pesticides discharged into the environment is expected to increase with the use of fungicides to treat infected soybean acres. Based on currently available, or likely to be available, soybean rust fungicides,[7] pesticide use (measured in active ingredient) is expected to increase by 0.10 - 0.20 pounds per treated soybean acre. In addition, as producers switch to alternative crops such as corn and cotton (requiring relatively intensive use of pesticides), there is likely to be an overall increase in pesticide use per cultivated acre in the United States. The quantities of nitrogen, phosphorus, and sediment discharged into surface and groundwater are also expected to change based on alternative crop rotations and production levels. In general, if a region cultivates fewer (more) soybean acres, then nitrogen and phosphorus loss through leaching and runoff would be expected to increase (fall).

World Trade Implications of Soybean Rust—Soybean-importing countries have been affected by soybean rust mostly in terms of its effect on the prices of South American exports. In recent years, production losses in Brazil and Paraguay related to soybean rust reduced the export potential of those countries, which contributed to strengthened global prices and likely supported more U.S. soybean exports than may otherwise have occurred.

This study is based on how the 2001 USDA baseline projections would change under an assumption of a soybean rust introduction in 2005. Given the 2001 USDA baseline, this analysis estimates that U.S. soybean exports would decline between 0.6 and 5.6 percent, depending on the extent and severity of a soybean rust outbreak (table 6). However, the current market outlook is considerably tighter than 2005's baseline projection. Poor weather has reduced recent U.S. soybean yields so that 2004/05 beginning stocks are forecast to be at their lowest level since 1977 and well below the projected level of the 2001 baseline. If soybean rust were introduced into the current market environment, the initial price impacts might be even stronger than suggested by the 2001 baseline. Conversely, if soybean rust appeared after a more normal supply balance was restored, the impact of this pathogen on U.S. soybean prices and exports would be moderated.

Conclusions and Caveats

Several implications can be drawn from this analysis. First, the U.S. agricultural sector as a whole exhibits a tremendous amount of resilience, even when it is buffeted by large yield or production cost shocks affecting a key agricultural commodity like soybeans. This conclusion follows from the observation that, after market adjustments take place, the aggregate impact of soybean rust establishment in the United States represents less than 1 percent of the value of agricultural economic activity. Factors explaining the U.S. agricultural sector's resilience include the availability of substitute crops in regions where soybean rust is anticipated to be most severe; the availability of alternatives to soybeans and its derivative products for

[6]Many of the scientists we consulted suggest that, given the numerous hosts for soybean rust and the high likelihood of wind-driven natural spread of rust, the possibility of instituting a successful program to eradicate or slow the advance of soybean rust spores, either in the United States or in South America, appears remote.

[7]See footnote 3.

consumption as soybean prices increase; and the availability of inputs and technologies to limit economic losses. The resilience predicted by the analysis is consistent with the observed response of the U.S. agricultural sector to past pest infestations, such as the recent shock to the soybean sector caused by soybean aphids. Over time, technological innovations spurred by the new soybean production environment can be expected to further soften the blow of soybean rust infestation.

Another general conclusion is that, because soybean rust affects each production region differently, there will be both winners and losers—even among soybean producers. The adverse effects of soybean rust will be most pronounced where rust breaks out, and outbreaks are more likely in U.S. production regions with agro-climatic conditions favorable for the pathogen. And in some of those vulnerable regions, soybean farmers may have few alternative planting choices that are as profitable as soybeans would be in the absence of soybean rust establishment. The analysis also suggests that crop producers in regions that are unaffected by soybean rust will gain from an infestation elsewhere. Further, given time to adjust, the national economic impact of a soybean rust infestation on producers of other crops is positive, which partially offsets the losses from reduced soybean production. The wide regional variation in economic impact estimates suggests that, faced with scarce resource constraints, program managers and policymakers may want to consider targeting pest monitoring and management resources to regions most vulnerable to soybean rust.

This analysis assumes that an effective soybean rust public surveillance and monitoring capability is in place, that cost-effective fungicides are available to treat soybean crops in amounts that are needed by farmers, and that public programs are available to provide farmers with the expertise needed to respond to a soybean rust infestation.

Since soybean rust has not arrived in the United States, any analysis of the biological and economic impacts of this pest on domestic soybean producers and the agricultural sector is subject to great uncertainty. These uncertainties include: when and where soybean rust might arrive in the United States; variation in the suitability of regional climates for the establishment and severity of rust establishment; potential yield and production cost impacts; availability and efficacy of soybean rust control alternatives; and the short- and long-term domestic producer responses to a new pest. This analysis required numerous assumptions regarding these uncertainties, and the reported results should be interpreted in this context. As additional scientific research is undertaken to refine or narrow these uncertainties, both the biological and economic impacts can be better measured.

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