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Control of Exotic Pests

Forecasting Economic Impacts

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Abstract

Dollar losses beyond the farm gate resulting from the entry and establishment of an exotic crop pest may far exceed the direct losses farmers incur. This case study uses an econometric-simulation model to estimate the benefits to U.S. agriculture of preventing entry or establishment of the exotic soybean pest, *Phakopsora pachyrhizi* Sydow. Seven scenarios with different disease losses in different soybean-producing regions are simulated. Productivity losses caused by the disease generally elevate growers' income levels because commodity price increases outweigh production losses for most growers.

Keywords

Econometric-simulation model, exotic pest, soybean, disease, soybean rust, quarantines, areawide programs, plant breeding, costs and benefits, forecasts

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Summary

Dollar losses beyond the farm gate resulting from the entry and establishment of an exotic crop pest may far exceed the direct losses that farmers incur. Crop losses large enough to raise commodity prices often benefit farmers financially. The magnitude of these gains depends on the distribution of crop losses; farmers with the smallest crop losses benefit most. Increased feed prices reduce the profits of dairy and livestock producers. Consumers face higher prices for processed foods, meat, and dairy products.

This study employs a frequently used econometric-simulation model, TECHSIM, to estimate the benefits to U.S. agriculture of preventing entry or establishment of the exotic soybean pest, *Phakopsora pachyrhizi* Sydow. The results of the case study are representative of forecasts based on estimates of economic behavior. The model is used to simulate seven scenarios for the spread of the pathogen and the establishment of the disease (soybean rust). In some scenarios, disease losses are confined to portions of the South. Other scenarios model increasing losses over wider areas, and the final scenario models 25-percent losses in all U.S. soybean acreage. The impact on average growers is the same whether or not all acres incur losses; that is, profits eventually increase. Other feed grain growers also receive this windfall. When only part of soybean acreage incurs losses, the remaining growers receive most of the gains. Profits increase because commodity price increases outweigh production losses for most growers.

This case study shows that the entry of exotic crop pests affects agriculture in two ways. Establishing new pests lowers production efficiency. A less obvious result is that new pests may cause a redistribution of income within the agricultural sector. Both features can influence the allocation of scarce resources among quarantine and eradication programs.

Commonly employed estimation methods for evaluating the monetary benefits of preventing pest losses may have overestimated reductions in production efficiency. These methods may have also grossly underestimated monetary losses for some sectors and overestimated losses for other sectors. This study, by contrast, shows that crop losses do not always reduce grower profits. Therefore, Government decisions to implement quarantines, inspections, areawide programs, or plant breeding to control exotic pests may be based on incorrect economic assumptions.

Control of Exotic Pests

Forecasting Economic Impacts

Fred Kuchler and Michael Duffy*

Introduction

This report presents a method for estimating the economic consequences to U.S. agriculture of introducing an exotic pest (for example, an insect, weed, or disease). A case study estimates the economic effects of introducing a soybean pathogen, *Phakopsora pachyrhizi* Sydow (hereafter referred to as *P. pachyrhizi*) into the United States. This case study shows that previous studies, which neglected or gave only cursory attention to economic interactions, generated incorrect forecasts of changes in production and economic welfare. That is, a frequently employed method of calculating the value of pest losses always leads to the conclusion that crop losses reduce grower profits. Considering all economic impacts, however, leads to opposite conclusions for some commodities. Hence, Government decisions to implement quarantines, inspections, areawide programs, or plant breeding as controls for exotic pests may be based on incorrect assumptions about the value of these programs to various groups. Existing economic tools mitigate these effects.

Background

A pest is any organism that is detrimental to humans and their activities. Exotic pests are defined as those pests that do not currently live in a given area (defined by either geographical or political boundaries). If such pests were to be introduced into a new area, they could cause economic losses.

Reduction in Productivity Caused by Exotic Pests

Some exotic pests have recently been introduced into the United States *(10)*.[1] The Mediterranean fruit fly, Japanese beetle, Dutch Elm disease, Hessian fly, and chestnut blight are examples of introduced pests. The chestnut blight all but eliminated the American chestnut tree from the Eastern United States *(16)*. The Hessian fly was estimated to cause up to a 50-percent yield loss in wheat until successful control measures were developed *(15)*. These examples show that crop losses are certainly attributable to introduced pests.

Exotic pests will continue to be a potential problem for U.S. agriculture for at least two reasons. Travel and commerce among regions have become faster and are nearly ubiquitous. This movement increases the likelihood of accidentially transporting crop pests. The spread of the gypsy moth is an obvious example of this phenomenon. The increasingly narrow genetic base of agricultural crops is yet another reason for suspecting future problems with exotic pests. The losses from the 1970 outbreak of southern corn leaf blight show the potential for this problem *(16)*.

Publicly Financed Pest Control Methods

There are many options for controlling introduced pests. Control decisions may be left up to the individuals whose fields, orchards, or livestock are directly affected. However, efficient (cost-minimizing for a given level of control and/or control-maximizing within a given budget) responses to the threat of pest damage sometimes require collective action. This type of response can take the form of voluntary agreements among neighboring farmers, Government-enforced farmer behavior, or Government actions that take place independent of farmer behavior. This latter approach can be the most efficient response when an exotic pest is considered both as capable of causing large losses and as poorly controlled by individual farmers. An aggressive, mobile, destructive pest could fit that category. We are not suggesting that the Government should undertake control of all such pests. Large potential losses coupled with poor individual controls are necessary, but not sufficient, conditions to justify Government action to make the most efficient use of pest control resources. Our analysis answers questions about

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[1] Italicized numbers in parentheses refer to items in the references at the end of this report.

the category of exotic pests for which Government-financed and Government-implemented control actions are most efficient.

Government actions that take place independent of farmer behavior can be employed in three general forms to reduce the impact of introducing exotic pests: (1) quarantines and inspections, (2) areawide programs, and (3) plant breeding. These publicly financed programs are potentially more efficient than their private-sector counterparts. The usefulness of each of the three methods depends on the type of pest, its mobility, its current location, and the crops it threatens. Quarantines and inspections are used to keep pests from entering new areas. Areawide programs are used to eradicate pests after they have entered an area. Plant breeding for pest resistance can lessen both potential and actual damage from an introduced pest.

National quarantines have been in effect since 1912. "The primary authority provided by the Plant Quarantine Act of 1912 is a means to control the artificial introduction of exotic plant pests associated with plants" (*13*, p. 253). Since then, other legislation has further strengthened and expanded the use of quarantines. Even State-level quarantines and inspections are not unusual. The number of pests that are intercepted indicates the effects of quarantines and inspections. The Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA) reported intercepting 133,000 plant pests in 1981 *(17)*. APHIS has primary responsibility for exotic pests and works with foreign and State governments to prevent the entry and spread of pests.

Areawide programs can be undertaken to eradicate an exotic pest once it is discovered. The most recent publicized example of such an areawide program was the California program against the Mediterranean fruit fly *(6)*. Most of the work to control the pest occurred in the summer of 1982. Areawide programs can take many forms. Both large-scale chemical applications and the release of the pest's parasites and predators have been employed. For some insect pests, sterile males can be released to disrupt mating and reproduction. Mandatory cultural practices can sometimes be initiated.

Plant breeding for resistance is another means of coping with exotic pests. Plant breeding can be undertaken before or after entry. Although plant breeding has occasionally been successful, it is the slowest of the three control methods.

The Hessian fly is an example of plant breeding after entry. This fly was supposedly introduced during the American Revolution in the bedding of the Hessian troops *(12)*. Breeding wheat varieties for fly resistance began in the thirties and continues. These resistant varieties, in conjunction with altered planting dates, have reduced the Hessian fly's effect from severe economic loss to only minimal loss.

Allocation of Control Resources and Techniques

Evaluating these pest control methods is problematical. It is usually hard to determine whether a method has worked or if other uncontrolled forces have removed the pest. Of course, there are a few cases where one can evaluate the employed technique. Quarantines were successful in preventing reentry of the black potato wart *(16)*. But, the Dutch elm disease, chestnut blight, and European corn borer all entered despite quarantines. Conclusions about the efficacy of control methods for most exotic pests are difficult to draw.

The optimal allocation of resources to control exotic pests is not obvious. Researchers cannot accurately determine the possible production losses due to particular exotic pests. Without this knowledge, researchers neither know which pest is able to cause the greatest dollar losses nor which control method is most effective. The dollar value of any type of pest control action to any subsector of the agricultural economy is an unknown.

Because there is no fully satisfactory means of projecting the damage an exotic pest can do, forecasting presents problems. By definition, researchers have no data on the damage an exotic pest could cause in a new area. A pest may have little or no economic importance in its native area because of the natural system of checks and balances. But, when introduced into an area with a favorable climate, a susceptible host, and without natural enemies, the pest population can dramatically increase and cause significant losses. What may be a suitable environment in a new area may not support pest development for reasons that are unknown. Forecasting crop losses accurately is difficult even with common pests. For exotic pests, the ordinary problems of assessing crop loss are compounded with new levels of uncertainty.

Despite difficulties in obtaining results, we clearly need a quantitative analysis that yields accurate and justifiable forecasts of welfare effects from different programs. This type of analysis has obvious utility for Government decisionmakers. The monetary impact of introducing or controlling an exotic pest may have consequences far beyond the farms where pest losses occur. Implementing a control program (or neglecting to do so when pest losses are imminent) will affect growers of other crops, processors, consumers, and other groups throughout the marketing chain. These welfare effects may often be larger than the effects on growers. Thus, the distributional effects, as well as the efficiency consequences, must be considered for each control option. Regardless of the decision criteria employed in selecting control programs, the success of a decision made without full information would be a random matter.

Decisionmakers face a multitude of options for allocating pest-control resources. Many different control techniques (and combinations of techniques) can be used on a given pest. The best mix of quarantines, areawide programs, and plant breeding must be determined for each pest. If time permits and if an exotic pest has the potential for extreme losses, efficiency may dictate breeding programs to avoid catastrophic losses from that pest's introduction. In other situations (for example, the California Medfly infestation), massive areawide programs must be initiated immediately. Selection from among the many feasible options for controlling exotic pests represents no trivial problem. Each option has different costs, different speeds of effectiveness, and different methods. (Effective quarantines and inspections may prohibit or slow entry of the pest for a while. This outcome distinctly differs from that of areawide programs or plant breeding which attempt to make inhospitable what is currently an attractive environment for the pest.)

Two principal factors contribute to uncertainty in deciding how to optimally allocate resources to control exotic pests. First, knowledge of physical crop losses a pest might cause is uncertain at best. Second, even if these losses could be accurately forecasted, the performance of different control options would be difficult to predict.

Many pests can be considered capable of causing crop losses. Attempting to control one pest may, with limited resources, preclude controlling another. Thus, the attempt to control a combination of pests complicates decisionmaking. That is, one must decide which pest poses the threat of greatest losses, whose losses (that may be prevented) are most important, and then how to prevent or stop pest losses.

Benefits of Preventing Entry of Exotic Pests

Estimating the costs of preventing or stopping an exotic pest is relatively straightforward. The real problem lies in estimating the benefits. It is not desirable to introduce a pest, even on a limited scale, to study how it will react in a new environment. Accidental releases can lead to disastrous results. One can estimate costs by drawing on past experiences for similar programs; however, benefit estimations are less direct.

A commonly employed method to bypass the problems of uncertainty is to use a simple, but specious, approach. This method is to ask biologists familiar with the threatened crops for their best guess of the physical losses. These estimates are then evaluated at current commodity prices. This dollar figure is posited as the total cost of the introduction of the pest or as the total benefit of eradicating or successfully quarantining the pest. Although the first step in this method is unscientific, resource constraints may make experts' opinions the best source of information. The problem with this method is the way it uses crop loss estimates to generate the value of losses. It ignores economic incentives and market forces, which means that these noneconomic forecasts are likely to be incorrect, not only in orders of magnitude, but also in direction of change.

Noneconomic forecasts are simple to generate and offer a simple way to interpret results. With the entire set of impacts collapsed into a single dollar figure, optimally choosing both pest control techniques and the set of pests to control is easy. Consider first the case in which available pest control techniques are all able to control the threatening pests. If the value of the loss figure were correct, it would be equivalent to the benefits received from control. Dividing this figure by costs of control is a benefit/cost ratio. The largest of these figures shows the pest and pest control technique for which the value of agricultural production saved per dollar of control costs is maximized. The problem is only a little more complex when control techniques are not perfectly effective. Benefits must be the losses that each control technique would prevent, which may be less than the value of these losses. This figure would be estimated in the same way as the value of the loss figure, and analysis could proceed as in the former case. It is unfortunate that the results are still unreliable.

The following example shows how an econometric-simulation model can provide sufficiently detailed information for one to make policy decisions about publicly financed pest-control programs. Not only can one account for market forces in generating information for policy decisionmaking, but one can examine many different options, regardless of their realism. The following example shows some ways to use economic tools in policy analysis. It does not show what ought to be done, only what might happen if nothing were done. In this way, one can derive an opportunity cost measure. To answer questions of policy analysis, one would require additional modelling that incorporated cost and effectiveness of different controls.

Our example demonstrates how one can use an econometric-simulation model to forecast the efficiency (how much can be produced) and the distributional consequences (who receives the benefits of production) of introducing a virulent and aggressive soybean pathogen into the United States. The pest in question, *P. pachyrhizi*, incites soybean rust, a disease of soybeans. This disease has been characterized as an "increasingly. . . threatening plant disease" and in "Taiwan, Thailand, and eastern Australia,. . . [is] the most economically important fungal disease of soybean" *(1)*. This pest can be considered as an exotic pest because it has not yet been recorded in fields in the United States.

All three types of Government-financed programs could be instituted to counteract or slow the development and impact of the rust pathogen. If this pathogen were to become established in the United States, a large area program might be demanded. Although the performance of chemical pesticides against the rust pathogen in the United States is unknown, the technology for chemical treatment exists. However, other types of programs could also be considered. With accurate forecasts of the welfare impacts from entry of the pathogen and establishment of the disease, researchers could answer questions concerning whether effective Government programs would be worth the costs. Knowledge of the distribution and magnitude of the gains and losses of establishing the pest would also clarify the type of program that might be politically viable.

This pest presents an interesting forecasting problem for several reasons. Trying to predict without benefit of historical precedent is difficult—both in using quantitative tools and in deriving numerical forecasts. The desired economic analysis would use quantitative data of crop loss assessment as inputs to show changes in prices, quantities, and economic welfare of different sectors of the agricultural economy. However, the biological activity of *P. pachyrhizi* in the United States is an unknown. In this case, the problem of gleaning numerical results for changes in the welfare of soybean farmers, feed grain growers, livestock and poultry growers, and consumers appears intractable.

The particular case of soybean rust is interesting because, where the pathogen currently exists, the resulting disease can substantially reduce soybean yields. Biologists worry that the pathogen might enter and, even worse, might survive in the United States. McGregor has identified soybean rust as a major disease of soybeans *(10)*. His report listed this soybean pathogen in the top 25 of the 100 most dangerous exotic pests and estimated that losses from soybean rust might be as high as 50 percent per acre (*10*, p. 55). Bromfield has summarized the available data on losses from the disease *(1)*. Losses above 50 percent have occurred in individual fields in some parts of Asia (1, p. 252). Losses of up to 60 percent have occurred in greenhouse conditions in the United States. We can thus conclude that the McGregor estimate is not extreme.

Some races of the pathogen have been discovered in soybean fields in Brazil and the Carribean in recent years. This finding is important because it confirms Bromfield's admonitions that the disease could be significant outside Asia and Oceania *(1)*. He also claims that the fungus has been identified in four African nations and that *P. pachyrhizi* might have been identified by another name in Guatemala and in four Carribean nations. In a later paper, Bromfield reports additional findings of the pathogen:

> In equatorial Africa, *P. pachyrhizi* has been reported from Sierra Leone, São Tomé, Ghana, Nigeria, Uganda, Zaire, Sudan, Ethiopia, Tanzania, and Zambia. In the Americas, the pathogen has been reported. . . on a number of legumes from several countries: Brazil, Cuba, Puerto Rico, and Guatemala (*2*, p. 252).

Researchers now know that outside the Orient soybeans are a host for the pathogen. Because international trade and travel are now commonplace, the pathogen could enter the United States accidentially. Furthermore, soybean breeding stock is routinely transferred among countries. Fungal pests can travel with seed stock and are difficult to detect in that state. The soybean rust pathogen could clearly enter the United States from several sources.

Because there are no U.S. field data on the behavior of soybean rust, projections of its behavior in the United States must be extrapolated from field observations in areas where it is endemic. Therefore, expert opinion must be the basis for the assumptions we use to derive estimates of the economic consequences of introducing *P. pachyrhizi.* One must be aware that changes in these assumptions can significantly affect the resulting analysis.

Loss Simulation

To analyze the possible economic consequences of introducing the soybean rust pathogen into the United States, we employed TECHSIM, an econometric-simulation model of the seven major field crops: soybeans, corn, grain sorghum, wheat, barley, oats, and cotton *(5).* This supply-demand model was specifically designed for use in analyses of regulation and technological change. For example, researchers use it to investigate the economics of situations in which Environmental Protection Agency regulations forbid the use of commonly used pesticides. In that situation, farmers are forced to substitute more expensive and/or less effective pest control measures. One can also use the model to investigate technological changes like the use of new pesticides (for example, chemicals that reduce costs of production or increase yields). The introduction of *P. pachyrhizi* would be a kind of technological change, albeit negative. The version of TECHSIM used in our analysis did not include an explicit livestock sector, but it is otherwise the same as the model specified by Collins and Taylor.

In TECHSIM, estimated supply and demand functions for each commodity and some processed products were linked in a recursive adjustment model. On the supply side, annual production of each commodity is based on relative expected profitability of each commodity. Thus, farm-level decisionmaking with the goal of profit maximization determines annual production, the major component of supply. When cost of production or per-acre productivity of a specific crop is altered, the profitability of the crop relative to all others is altered, thereby shifting crop acreage and production. We trace these effects through the model to alter commodity prices, farm income, income distribution, exports, and inventories. Actual farm income determines expected farm income for the following year and thereby provides the recursive link between forecasted yearly changes.

Introducing the pathogen and establishing the disease would change the opportunities farmers face; it would reduce the productivity and thereby the relative profitability of infected acreage. This change can be represented by the manipulable variables in the model. These variables (per-acre production and per-acre cost of production) represent the farm-level changes occurring under regulatory or technological change. In TECHISIM, these measures can be altered in any or all of 13 production regions on any or all commodities. The impact of national- or regional-specific changes can be modeled. The model yields results over a multiyear period.

Table 1 separates the United States into 13 distinct producing regions. Table 2 presents baseline forecasts from the model without unexpected technological changes. Forecasted values for important economic variables are shown for 5 consecutive years. This table is included so that there is a base with which changes in these values can be compared. Only 5 years of forecasts are presented because when changes in per-acre productivity or per-acre costs of production are introduced, only minor adjustments in any of the important forecasted variables occur beyond 5 years. Fifth-year data provide a good approximation of new equilibrium values.

Scenarios for Disease Development

Before analyzing the economics of soybean rust, we first estimated how the soybean rust pathogen might behave in terms of per-acre yield losses and area infected. This process was difficult because it is uncertain where the pathogen might enter, the

Table 1—Regional demarcation for TECHSIM

Region	States
1	Washington, Oregon
2	California
3	Idaho, Montana, Wyoming, Nevada, Utah, Colorado
4	Arizona, New Mexico
5	Nebraska, Kansas
6	North Dakota, South Dakota
7	Oklahoma, Texas
8	Minnesota, Wisconsin, Michigan
9	Iowa, Missouri, Illinois, Indiana, Ohio
10	Arkansas, Louisiana, Mississippi
11	Alabama, Georgia, South Carolina, Florida
12	Kentucky, West Virginia, Virginia, Tennessee, North Carolina
13	Mid-Atlantic States, New England

speed at which it might spread, the areas that might be infected, the severity of infection and its impact on yield, the ability of the pathogen to overwinter, and the feasibility of chemical controls. With this degree of uncertainty, the possible range of outcomes is enormous. The endpoints of this range are so far apart that an analysis based on extremes would leave us with the conclusion that anything could happen. However, plant pathologists at USDA's Plant Disease Research Laboratory in Frederick, Md., suggested several possible scenarios. These scenarios were not designed as an exhaustive list of possibilities of disease behavior, but each represents a different class of behavior. No scenario can be assumed as most (or least) likely.

We based our analysis of the economics of soybean rust on three different environmental assumptions and two different soybean grower responses. The three environments are described in terms of the ultimate extent and severity of the infection. We assume that conditions which would encourage the disease to spread would also exacerbate losses in any given area. We further assume that, in each case, the disease would first appear in the southern Mississippi Valley because its climate is analogous to areas of the Orient where the disease is severe. The Mississippi Valley also supports an array of cultivated and wild legumes that could serve as hosts, allowing the pathogen to survive the winter. In the first environment, the disease is assumed to permanently establish itself in the Southern United States during the second year after entry. In the second environment, the disease is assumed to breach the area and grow from its entry in the Mississippi Valley to infect acreage in the Corn Belt as well as in the South. With this more extensive infection, disease losses (per acre) are assumed to be greater. The third environment assumes that climatic differences would have little impact on the disease's ability to spread; it would infect the entire U.S. soybean-producing area. Per-acre losses would be greater than in the second environment. The only assumed impact of climate is that yield losses beyond the western, northern, and eastern perimeters of the Corn Belt would be less severe than would losses in the South and Corn Belt.

For each environment, we assumed two patterns of soybean grower behavior: (1) no response and (2) aerial spraying of the crop with a fungicide. We thought the first pattern was plausible because using fungicides against the disease under U.S. environmental conditions is unknown. Furthermore, fungicides and spray equipment may not be sufficient to allow for any response. The second case must also be considered possible because chemical control recommendations exist where soybean rust exists *(1)*. Assuming that fungicides could be applied, we assumed aerial spraying costs to be $10 per acre and postulated one, two, or three sprays depending on the severity of the disease.

Three environments and two potential grower responses led to modelling a combination of six scenarios. A seventh scenario represents a massive spread of the disease in which the entire soybean-growing area of the United States is assumed to suffer an infection. The infection is assumed to appear throughout the United States in a single growing season. Losses are sustained continually after appearance of the infection. Table 3 describes all the scenarios.

One can use table 3 to derive a general idea of the estimates of USDA's Plant Disease Research Lab pathologists concerning the usefulness of fungicides in preventing disease losses. Comparisons of disease losses without control with losses when control is attempted show that the plant pathologists believe

Table 2—Base forecast: U.S. soybean supply and demand

Year	Planted acres	Production	Supply	Price	Exports
	Millions	*Billion bushels*	*Billion bushels*	*Dollars/ bushel*	*Million bushels*
1982	57.660	1.5591	1.7335	6.80	589.100
1983	57.695	1.5602	1.7349	6.78	589.533
1984	57.721	1.5612	1.7361	6.75	590.000
1985	57.744	1.5621	1.7372	6.72	590.500
1986	57.765	1.5630	1.7383	6.69	591.017

fungicide spray programs would reduce, but not eliminate, the impact of the disease. The difference in losses between treatment and nontreatment generally suggests that as disease pressure (and hence potential crop loss) increases, the percentage of the crop saved by applying fungicides increases. This benefit results from more intensive fungicide use under high pest pressure. Fungicides also kill larger proportions of pathogen populations when populations are larger than when they are small.

Tables 4 to 10 show the five yearly forecasted changes depending on the environment assumed and the growers' response. These are forecasted changes (not absolute levels) for the welfare effects (profits) to soybean producers by region. The tables also show the impacts on producers of other commodities, processors, forward industries, and consumers.

Note that the assumed behavior of the disease is simplistic. Per-acre losses are assumed to grow to equilibrium values. Losses are assumed identical, year to year, once these levels are reached. Surely no disease would behave in such an unvarying manner. In some years, changing weather and environmental conditions would induce the pathogen to spread and cause substantial losses. In other years, farmers might find disease losses trivial. Because information on the distribution of good and bad years for disease severity is not available, we employed the assumed average constant values.

Analysis of Results

In the first environment (limiting the disease to the South and assuming no grower response), a 3-percent per-acre yield loss was introduced in 1982 in region 10 (Arkansas, Louisiana, and Mississippi—the lower Mississippi Valley) and a 7-percent per-acre yield loss was introduced in regions 7, 10, and 11 for 1983 and beyond. In the affected areas, this yield loss amounts to about 1.5 bushels per acre. In 1982 and 1986, aggregate U.S. losses would be less

Table 3—Scenarios

1. **Environment 1 with no response**
   Year 1—3-percent yield decrease, Region 10
   Year 2 and beyond—7-percent yield decrease, Regions 7, 10, 11

2. **Environment 2 with no response**
   Year 1—3-percent yield decrease, Region 10
   Year 2 and beyond—13-percent yield decrease, Regions 7, 9, 10, 11, 12

3. **Environment 3 with no response**
   Year 1—3-percent yield decrease, Region 10
   Year 2 and beyond—25-percent yield decrease, Regions 5, 7, 9, 10, 11, 12
   15-percent yield decrease, Regions 6, 8, 13

4. **Environment 1 with response**[1]
   Year 1—1-percent yield decrease, $10 cost increase, Region 10
   Year 2 and beyond—4-percent yield decrease, $10 cost increase, Regions 7, 10, 11

5. **Environment 2 with response**[1]
   Year 1—1-percent yield decrease, $10 cost increase, Region 10
   Year 2 and beyond—7-percent yield decrease, $20 cost increase, Regions 7, 9, 10, 11, 12

6. **Environment 3 with response**[1]
   Year 1—1-percent yield decrease, $10 cost increase, Region 10
   Year 2 and beyond—15-percent yield decrease, $30 cost increase, Regions 5, 7, 9, 10, 11, 12
   10-percent yield decrease, $20 cost increase, Regions 6, 8, 13

7. Massive entry—25-percent yield decrease, Regions 5, 6, 7, 8 , 9, 10, 11, 12, 13

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[1] Growers are assumed to respond with aerial applications of fungicides. Each application increases costs $10 per acre.

Table 4—Environment 1: No grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust: Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-6.970	-6.970	0.07	-1.25
1983	.119	-20.059	-20.626	.25	-4.45
1984	.363	-12.669	-14.752	.31	-5.40
1985	.531	-7.934	-10.751	.31	-5.48
1986	.582	-6.422	-9.389	.31	-5.40

Year	Changes in soybean profits per acre caused by soybean rust, by region: 5	6	7	8	9	10	11	12	13
	Dollars								
1982	1.78	1.49	1.69	1.90	2.15	-2.99	1.53	1.66	1.93
1983	6.35	5.29	-5.74	6.75	7.67	-5.30	-5.19	5.91	6.87
1984	7.70	6.42	-4.50	8.19	9.30	-4.16	-4.07	7.18	8.33
1985	7.78	6.52	-4.35	8.32	9.44	-4.02	-3.93	7.28	8.46
1986	7.71	6.43	-4.40	8.21	9.32	-4.06	-3.97	7.19	8.34

Year	Selected economic impacts caused by soybean rust: Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	62.29	62.29	34.08	-144.02	-47.66
1983	31.82	245.07	279.89	115.19	-551.52	-155.77
1984	128.34	368.48	509.38	128.12	-786.14	-155.05
1985	199.27	400.04	627.31	124.47	-895.84	-155.36
1986	215.56	401.77	657.88	122.47	-924.90	-154.58

[1] Environment 1 is the least favorable for rust development; spread is confined to nine Southern States. No grower response assumes farmers do not react with additional pest control.

than 0.5 percent. The resulting changes in soybean prices do not affect the macroeconomy. However, there are distributional consequences for domestic soybean growers. Growers in infected areas suffer reduced rents (profits), whereas all other growers enjoy slightly higher prices. The Corn Belt producers fare best, eventually receiving over $9 more per acre. Changes in aggregate corn, soybean, and total crop rents show that rents to feed grain growers generally increase as a result of higher feed grain prices. Consumers eventually feel the impact in higher prices of beef, pork, and poultry. Livestock producers and meat processors all pay higher prices for their inputs. Total losses to consumers and industries beyond the farm gate would eventually exceed $900 million annually.

The heading, "Forward industry rents and final consumer surplus," in the boxheads of tables 4-10 refers to the sum of losses to consumers (that is, higher prices for livestock products and processed foods) and to all industries beyond the farm gate that depend on soybeans and their processed products (for example, feedlot operators, slaughter houses, and retail grocery stores). One should expect that if farm gate prices rise, at least part of that increase would be passed forward. That is, firms which first process raw agricultural commodities will face higher input prices. Here, industry rents will be reduced. With higher costs, output from this industry should be reduced, thereby driving prices for the processed product higher and partially (but not completely) mitigating the rent reduc-

Table 5—Environment 1: With grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust				
	Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-2.324	-2.324	0.02	-0.417
1983	.003	-13.024	-13.207	.15	-2.617
1984	.067	-10.231	-11.431	.21	-3.617
1985	.214	-6.079	-7.929	.21	-3.750
1986	.263	-4.612	-6.645	.21	-3.700

Year	Changes in soybean profits per acre caused by soybean rust, by region								
	5	6	7	8	9	10	11	12	13
	Dollars								
1982	0.59	0.50	0.56	0.63	0.72	-10.99	0.51	0.55	0.64
1983	3.73	3.11	-13.09	3.96	4.50	-12.85	-12.79	3.47	4.03
1984	5.17	4.31	-11.75	5.50	6.24	-11.62	-11.58	4.81	5.59
1985	5.35	4.46	-11.56	5.69	6.46	-11.44	-11.41	4.98	5.78
1986	5.28	4.40	-11.59	5.62	6.38	-11.47	-11.44	4.92	5.71

Year	Selected economic impacts caused by soybean rust					
	Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	-84.38	-84.38	11.41	-48.13	-121.10
1983	10.64	-10.13	-2.09	70.75	-308.67	-238.74
1984	62.25	99.17	157.89	90.60	-480.24	-237.79
1985	117.63	131.20	250.34	88.56	-562.93	-236.06
1986	133.38	134.89	280.40	86.73	-592.13	-235.20

[1] Environment 1 is the least favorable for rust development; spread is confined to nine Southern States. With grower response assumes farmers respond with an aerial fungicide application that increase costs $10 per acre.

tion. Again, this situation represents a cost increase for firms which purchase the processed product. In this manner, industry rents may be reduced throughout the marketing chain as the price increase is passed forward to consumers. Prices should be higher and output lower throughout the marketing chain. Just and Hueth showed that in vertically related industries[2] one can measure the sum of these losses to consumers and producers *(9)*. Losses to producers are the sum of all rents lost throughout the marketing chain. Losses to consumers (reductions in consumer surplus) can be measured by the difference between what consumers are willing to pay to acquire goods and what they have to pay in the market. Chavas and Collins have generalized Just and Hueth's analysis to include technological change or distortion *(4)*. For example, a pesticide regulation that prohibits the use of a commonly employed chemical would make some farm operations less efficient.

Such a technological change would reduce farm rents. Reduced farm output and/or higher prices would reduce rents to all producers involved in transforming farm commodities into final consumed goods. Although the sum of producer rents and consumer surplus represents gains or losses to a very large and diverse group, it does indicate some

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[2] Vertically related industries are those in which the output from one industry is an input for another industry up the marketing chain.

Table 6—Environment 2: No grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust				
	Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-6.970	-6.970	0.07	-1.250
1983	.119	-172.794	-173.361	1.80	-31.800
1984	1.954	-127.427	-141.810	2.52	-44.533
1985	3.524	-88.820	-110.749	2.75	-48.533
1986	4.276	-69.608	-95.592	2.81	-49.567

Year	Changes in soybean profits per acre caused by soybean rust, by region								
	5	6	7	8	9	10	11	12	13
	Dollars								
1982	1.78	1.49	1.69	1.90	2.15	-2.99	1.53	1.66	1.93
1983	45.73	37.84	16.39	48.27	20.86	15.13	14.80	16.09	49.08
1984	63.53	52.99	31.46	67.60	40.05	29.05	28.42	30.89	68.72
1985	69.25	57.77	36.27	73.69	46.18	33.49	32.77	35.62	74.92
1986	70.71	58.99	37.56	75.24	47.83	34.69	33.94	36.89	76.50

Year	Selected economic impacts caused by soybean rust					
	Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	62.29	62.29	34.08	-144.02	-47.66
1983	31.82	1,320.28	1,355.11	741.83	-3,442.08	-1,346.48
1984	384.59	2,644.21	3,029.82	1,003.32	-5,354.28	-1,364.61
1985	907.82	3,255.83	4,259.18	1,096.41	-6,653.32	-1,355.12
1986	1,167.86	3,479.26	4,840.76	1,136.86	-7,281.52	-1,356.50

[1] Environment 2 assumes the rust spreads to 14 Southern States and 5 Midwestern States. No grower response assumes farmers do not respond with additional pest control measures.

distinctions in the distribution of gains and losses resulting from production losses. Producers still able to grow soybeans will find their operations more profitable, whereas demanders of soybeans, consumers, and all intermediaries between producers and consumers will find they are substantially worse off when soybean production falls.

The 1982 losses, with no grower response, were assumed identical in environments 1 and 2. Thus, the economic impacts of introducing the pathogen were identical for the two environments for 1982. In all modelled years beyond 1982, 13-percent per-acre losses were assumed for the South and Corn Belt (regions 7, 9, 10, 11, and 12) for environment 2. Soybean production is forecasted to fall 11 percent in 1983, and soybean price is forecasted to rise 42 percent by 1986; exports are forecasted to fall 8 percent. Rent per acre rises in each region, although not all areas are infected. This increase occurs because the soybean demanders perceive few good substitutes for soybeans. Characteristically, prices rise proportionately faster than quantities marketed fall. The percentage of per-acre losses specified in the seven scenarios was intended to reflect average losses rather than losses every grower would experience. That is, some growers would suffer extensive losses, whereas others might find their fields untouched by the disease even in infected areas. Averaging losses across all growers shows that the losses sustained would be proportionately smaller than the price increase that all growers would face.

Table 7—Environment 2: With grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust				
	Planted acres	Production	Supply	Price	Exports
	Millions	Million bushels	Million bushels	Dollars/ bushel	Million bushels
1982	0	-2.324	-2.324	0.02	-0.417
1983	.003	-94.369	-94.552	.97	-17.183
1984	.124	-90.845	-98.595	1.58	-27.833
1985	1.266	-61.846	-75.779	1.76	-31.167
1986	1.842	-46.868	-63.435	1.81	-31.917

Year	Changes in soybean profits per acre caused by soybean rust, by region								
	5	6	7	8	9	10	11	12	13
	Dollars								
1982	0.59	0.50	0.56	0.63	0.72	-10.99	0.51	0.55	0.64
1983	24.51	20.44	-9.72	26.08	-6.91	-10.51	-10.71	-9.90	26.51
1984	39.71	33.13	3.74	42.25	10.23	1.92	1.45	3.31	42.96
1985	44.45	37.08	7.97	47.30	15.61	5.83	5.27	7.47	48.09
1986	45.53	37.98	8.97	48.44	16.88	6.75	6.17	8.45	49.25

Year	Selected economic impacts caused by soybean rust					
	Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	-84.38	-84.38	11.41	-48.13	-121.10
1983	10.64	-207.21	-199.18	434.49	-1,914.57	-1,677.99
1984	-33.16	719.21	611.50	673.51	-2,963.21	-1,698.19
1985	234.02	1,164.78	1,335.38	744.87	-3,711.71	-1,673.80
1986	442.86	1,318.65	1,759.67	767.51	-4,169.38	-1,680.91

[1] Environment 2 assumes the rust spreads to 14 Southern States and 5 Midwestern States. With grower response assumes farmers respond with two aerial fungicide applications that increase costs $20 per acre.

Because each bushel of soybeans would be far more valuable, total revenues received would increase. With no change in costs, an increase in revenues would mean an increase (on average) in net returns. However, the uninfected areas would benefit most, receiving over $70 per acre in additional revenues. Total crop rent would increase nearly $5 billion, but consumer losses and losses to industries beyond the farm gate would increase over $7 billion.

Net losses amount to $1.3 billion in most years. This situation involves more than a direct transfer from one group to another. The column in tables 4-10 with the heading, "net losses," is the sum of losses and gains across each of the modelled sets of economic agents. This figure was intended by the model's authors to measure changes in aggregate or social welfare and could serve as a guide to policy. Whether or not adding up dollar income of each group is a meaningful measure of social welfare, these figures highlight some of the important features one might anticipate from the soybean crop losses. Although feed grain growers and meal and oil producers may markedly benefit from introducing the pathogen, this group collectively could in no way compensate the group that loses. That is, there is no way that reducing soybean production efficiency can make everyone wealthier. Although this point is obvious, the net losses column does reinforce the conclusion that a new soybean disease in the United States would have deleterious consequences. The importance of this loss in production

Table 8—Environment 3: No grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust: Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-6.970	-6.970	0.07	-1.250
1983	.119	-328.278	-372.845	3.82	-67.217
1984	2.597	-320.901	-351.334	5.85	-103.127
1985	5.926	-251.456	-303.440	6.80	-120.117
1986	7.916	-209.203	-272.737	7.25	-128.083

Year	Changes in soybean profits per acre caused by soybean rust, by region: 5	6	7	8	9	10	11	12	13
	Dollars								
1982	1.78	1.49	1.69	1.90	2.15	-2.99	1.53	1.66	1.93
1983	29.56	46.94	28.04	59.87	35.70	25.90	25.34	27.54	60.87
1984	67.93	83.14	64.45	106.05	82.06	59.51	58.22	63.29	107.83
1985	86.19	100.32	81.77	121.97	104.11	75.51	73.88	80.31	130.11
1986	94.90	108.47	90.03	138.37	114.63	83.14	81.34	88.42	140.68

Year	Selected economic impacts caused by soybean rust: Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	62.29	62.29	34.08	-144.02	-47.66
1983	31.82	2,012.26	2,046.89	1,266.24	-6,567.06	-3,255.28
1984	588.86	4,931.30	5,467.46	1,961.51	-11,079.49	-3,736.93
1985	1,673.41	6,876.00	8,650.34	2,437.73	-14,865.22	-3,908.49
1986	2,368.42	7,953.52	10,633.91	2,741.50	-17,243.01	-3,999.85

[1] Environment 3 is the most favorable for rust development. All soybean-producing States would be infected. No grower response assumes that farmers do not respond with additional pest control measures.

efficiency can be missed if policy concerns do not go beyond the farm gate.

In environment 3 with no grower response, the disease is introduced into the lower Mississippi Valley in 1982 and infects all U.S. soybean-producing regions by 1983. This loss is partially assuaged as higher prices (more than double) encourage increases in planted acreage. Exports fall almost 22 percent. The higher prices benefit growers in all regions. Once again, even though rents to soybean growers may increase almost $8 billion, this gain is more than offset by consumer losses and losses to industries beyond the farm gate.

When soybean growers were assumed to be able to control, but not eradicate, the disease with aerial applications of fungicides, the disease had less impact. In environment 1 with this grower response, we assumed a 1-percent yield loss per acre in region 10 for 1982 and a 4-percent loss per acre in regions 7, 10, and 11 (the South) for 1983. We also assume a $10-per-acre cost increase to cover fungicide and spray costs. Southern growers would then lose over $11 per acre, whereas all others would enjoy a $0.21-per-bushel price increase. Soybean growers would benefit ($135 million) while everyone beyond the farm gate would lose ($300-600 million annually beyond 1982). Net losses would exceed $235 million annually.

Table 9—Environment 3: With grower response[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust				
	Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-2.323	-2.323	0.06	-0.983
1983	.058	-224.571	-225.004	5.36	-94.650
1984	4.193	-129.829	-172.446	5.05	-89.217
1985	4.856	-112.797	-160.730	5.00	-88.250
1986	5.242	-103.481	-151.965	4.85	-85.717

Year	Changes in soybean profits per acre caused by soybean rust, by region								
	5	6	7	8	9	10	11	12	13
	Dollars								
1982	1.39	1.16	1.32	1.48	1.68	-10.28	1.19	1.30	1.51
1983	59.16	67.14	54.59	91.16	77.70	48.11	46.42	53.08	93.01
1984	52.87	61.48	48.62	83.94	70.10	42.60	41.03	47.21	85.67
1985	51.68	60.43	47.49	82.60	68.66	41.56	40.01	46.10	84.31
1986	48.79	57.82	44.75	79.27	65.18	39.03	37.54	43.41	80.93

Year	Selected economic impacts caused by soybean rust					
	Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	9.00	-34.71	-27.80	14.87	-107.45	-120.95
1983	899.03	3,949.17	4,645.14	1,203.61	-9,531.75	-3,740.23
1984	1,672.18	4,329.16	5,983.16	1,786.47	-11,520.38	-3,845.24
1985	1,725.07	4,392.11	6,313.01	2,015.73	-12,174.98	-3,944.68
1986	1,638.86	4,273.95	6,217.52	2,084.15	-12,137.39	-3,912.02

[1] Environment 3 is the most favorable for rust development. All soybean-producing States would be infected. With grower response assumes that farmers in the Southern and Midwestern States respond with three aerial fungicide applications for a $30 per acre cost increase. Growers in the Northern States would use two sprays for a $20 per acre cost increase.

In environment 2 with two sprays ($20 per acre), yield reductions are held to 7 percent per acre beyond 1982. Prices quickly rise 27 percent and exports fall 5 percent as production falls 6 percent in 1983 and 3 percent in 1986. Most soybean growers would generally benefit from the higher prices due to the disease, but the growers in the uninfected areas would fare best.

Environment 3 represents 15-percent losses in the South and Corn Belt by 1983 with three sprays ($30 per acre) and 10-percent losses with two sprays ($20 per acre) elsewhere. Prices are forecasted to rise 7 percent by 1983 and exports to fall 16 percent. Higher prices raise net revenues to soybean producers, thereby inducing increases in planted acreage. However, even with this increase in acreage, total production is down 7 percent. After 1982, rents per acre are up in all regions and rents to feed grain growers increase approximately $6 billion annually beginning in 1984. However, $12 billion is transferred from consumers and from all industries involved in transforming the raw agricultural commodities into final goods. Calculated net losses are $3.9 billion.

The extreme case we examined was a sustained 25-percent loss per acre across U.S. soybean-producing regions beginning in 1982. With the price of soybeans more than doubling, exports fall 24 percent. To have impacts this small, planted acreage must be able to increase 16 percent. Gains to soy-

Table 10—Massive entry[1]

Year	Changes in U.S. soybean supply and demand caused by soybean rust				
	Planted acres	Production	Supply	Price	Exports
	Millions	*Million bushels*	*Million bushels*	*Dollars/ bushel*	*Million bushels*
1982	0	-389.766	-389.766	3.95	-69.783
1983	2.348	-342.872	-374.239	6.15	-108.550
1984	5.697	-275.456	-329.990	7.26	-128.100
1985	7.752	-233.807	-301.424	7.83	-138.250
1986	9.005	-208.464	-283.030	8.11	-143.217

Year	Changes in soybean profits per acre caused by soybean rust, by region								
	5	6	7	8	9	10	11	12	13
	Dollars								
1982	31.84	26.56	30.21	33.88	38.46	27.89	27.29	29.67	34.44
1983	73.47	61.29	69.70	78.18	88.75	64.37	62.97	68.45	79.48
1984	94.55	78.87	89.70	100.61	114.21	82.84	81.04	88.10	102.29
1985	105.60	88.09	100.18	112.37	127.56	92.51	90.51	98.39	114.24
1986	111.09	92.67	105.39	118.31	134.19	97.32	95.22	103.51	120.18

Year	Selected economic impacts caused by soybean rust					
	Corn profit	Soybean profit	Total crop profit	Soybean meal and oil profit	Forward industry rents and final consumer surplus	Net losses
	Million dollars					
1982	0	1,970.29	1,970.29	1,281.23	-6,673.07	-3,421.56
1983	595.28	5,019.52	5,559.98	2,011.50	-11,506.12	-4,022.77
1984	1,760.27	7,128.35	8,998.30	2,539.38	-15,692.82	-4,293.42
1985	2,529.14	8,367.89	11,235.79	2,897.41	-18,451.35	-4,459.61
1986	2,898.73	9,056.62	12,453.14	3,128.73	-19,943.30	-4,505.04

[1] Massive entry assumes a 25-percent yield decrease from 1982 for all soybean-producing States.

bean growers would eventually exceed $100 per acre. This increase would represent over 70 percent more revenues in many regions.

Because introduced crop losses are so large, the model forecasts must be treated skeptically. The forecasted changes in economic variables and welfare impacts are larger, in this case, than for any historical period. The components of the model are used to extrapolate far beyond the range of data from which they are estimated. A general conclusion about generating forecasts (point estimates) from regression analyses is that each equation's ability to forecast rapidly diminishes as the distance of predetermined variables from mean values increases. This problem is especially acute for this case. *A fortiori*, the theoretical basis for the estimated equations in the model exacerbates this problem. The mathematical theory used to specify the form of the model (envelope theory) yields estimates that are linear approximations of the "true" supply and demand functions. Many functions could be far less elastic outside the range of historical movements than they are in the model. The model may be grossly underestimating price and welfare changes for the extreme scenarios. However, the opposite case is also possible. With soybean prices increasing, alternative high-protein feed sources may become profitable to produce and market. Synthetic feed sources could become economically viable and could partially substitute for lost soybean production. That is, a price increase may induce development of a new technology and may reduce the forecasted price rise.

In examining the results of these scenarios, one should note that the assumed per-acre losses are quite small compared with the observed losses that Bromfield reports. If the United States were to prove a suitable environment for *P. pachyrhizi* and per-acre losses were to be as high as McGregor forecasted, all the economic impacts given here would be many times larger. Assuming the 25-percent loss scenario, almost $20 billion annually would be lost to consumers and industries beyond the farm gate; such a 50-percent loss would put extraordinary stress on U.S. agricultural production. The United States has produced over 60 percent of the world soybean crop in recent years *(18)*. Any significant reduction of U.S. production could not be quickly replaced by international competitors. Livestock and poultry production would be immediately and adversely affected by higher feed prices. Some bottlenecks to shifting away from the use of soybean meal could be anticipated for the poultry industry because current production methods employ buildings and capital equipment specifically designed to take advantage of inexpensive high-protein feeds. Introducing the pathogen would increase food prices for consumers and would limit the availability of final consumption goods.

Implications

Government policymakers can use simulation models of economic relations to more easily sort through proposed policies to find those with desired ends. Policy outcomes are also clearer when economic relations are properly specified.

Economic models can bridge the gap between technical knowledge and political decisions. Biologists have some understanding of the possible per-acre production losses from and the acreages affected by the introduction of an exotic pest. These effects, however, are only the initial pest-induced impacts. Directly employing these estimates for policy analysis requires assuming that nothing else occurs. There would be no knowledge gap if introduction of a pest and the resulting yield losses did not induce changes in planted acreage of the affected crop, substitution between crops, price changes, and substitution among livestock feeds. The biologists' knowledge of technical relations concerning losses would be sufficient. If these changes did not occur, the biologists' estimates of losses could be evaluated at current commodity prices. These figures would be values policymakers could employ in defending changes in expenditures of public funds. The resulting numbers might be labeled losses to growers, processors, livestock producers, or consumers (depending on the marketing level of the chosen price).

These numbers are certainly inaccurate. Changes in per-acre productivity will change aggregate crop production, thereby affecting crop prices. Farmers will then be forced to alter their planting decisions. The actual changes in the welfare of commodity suppliers and demanders may be quite different than those predicted when biological information is assumed sufficient (all economic forces are assumed to be nonexistent). Farmers can adjust their planting decisions, and soybean consumers can substitute feeds and oil sources. Thus, forecasts that consider the impact of economic incentives are likely to differ from forecasts that ignore those incentives.

The difference in economic and noneconomic forecasts comes about in two ways: (1) the noneconomic loss forecasts will consistently overestimate losses to growers, and (2) these forecasts usually ignore repercussions in markets for substitutable commodities, export markets, inventories, and consumers when these influences are substantial. The example we have used demonstrates the importance of both these points. Not only would a noneconomic forecast overestimate welfare changes to soybean suppliers and demanders, but it might also forecast a change in the wrong direction.

In the case of soybean rust, soybean growers are forecasted not to lose, but to gain, from production losses. Growers are modelled as being able to adjust their production decisions, but this reversal of expectations results principally because estimated soybean demand is not very responsive to soybean price changes; thus, price changes induce proportionately smaller changes in quantities demanded. That is, a very large price increase may be required to make soybean demanders reduce the quantities of soybeans they demand.[3] Small reductions in quantities marketed will raise the average price soybean demanders are willing to pay by a larger percentage. The noneconomic forecast holds prices constant; de-

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[3] Summing the various soybean demand components allows calculation of elasticity of demand at base simulation solutions. The measured price elasticity at the beginning of the simulation is −0.43.

mand is assumed to be perfectly elastic (inflexible prices). To say that prices of agricultural commodities respond to changes in production is no surprise. Futhermore, one should expect that if pests can affect available quantities of food and fiber, this effect can be traced to changes in commodity prices. Historical examples illustrate this point. In the mid-19th century, epiphytotics of potato late blight caused many Irish and Germans to immigrate to the United States (16, p. 11). One can ask, "What happened to food prices in their homelands to induce this mass migration?" In the 1870's, the coffee rust destroyed coffee plantations in Ceylon. After replanting in tea, the English altered their customs to favor tea *(11)*. Once again, the high price of coffee (relative to tea) resulting from pest losses encouraged a major social change. The organization of modern commodity markets allows information on factors forecasted to affect crop production and crop value (such as revised estimates of planting decisions, weather, and politics of support programs) to be almost instantly capitalized into commodity prices. There is no reason why pest damage should not also cause price changes.

Although the model may not capture all the possible adjustments of introducing an exotic pest, it is a major step towards producing the vector of welfare effects that policymakers need to construct or to administer Government programs. At the very least, they can base their policies on an evaluation of whether groups would be made better or worse off.

Ordish and Dufour discussed problems of neglecting economic forces in forecasting economic implications of losses from exotic pests *(11)*. They claimed that examining economic forces would lead to different predictions of pest impacts than would noneconomic forecasts. Although their examples showed analyses of only a small set of economic forces, their ideas have not been adopted. Recent examples of works that attempt to calculate the value of pest losses without considering economic effects are easy to find. Chandler, Drummond, and James have carried out the calculations that Ordish and Dufour first criticized *(3, 7, 8)*.

Neglecting the operation of commodity markets will cause at least some policies to be based on incorrect information. Decisions will be misguided. This problem is especially disturbing because, at one time, crop loss research and agricultural economic analysis were treated as complementary. Crop loss research incorporated rudimentary analysis of distributional, as well as efficiency, questions. Answers to both types of questions were sought as early as 1915:

> These estimates of losses due to insects are then very largely comparative. Yet, to a large extent, they are still real losses, the same as those occasioned by fire and storm; for though a small crop may bring better prices, it is usually at the expense of individuals or communities which have sustained exceptionally heavy losses *(14)*.

The sophistication of both fields has increased since 1915, but the obvious nature of complementarity has not. Instead of refining the forecasting art, specialization has taken us backwards.

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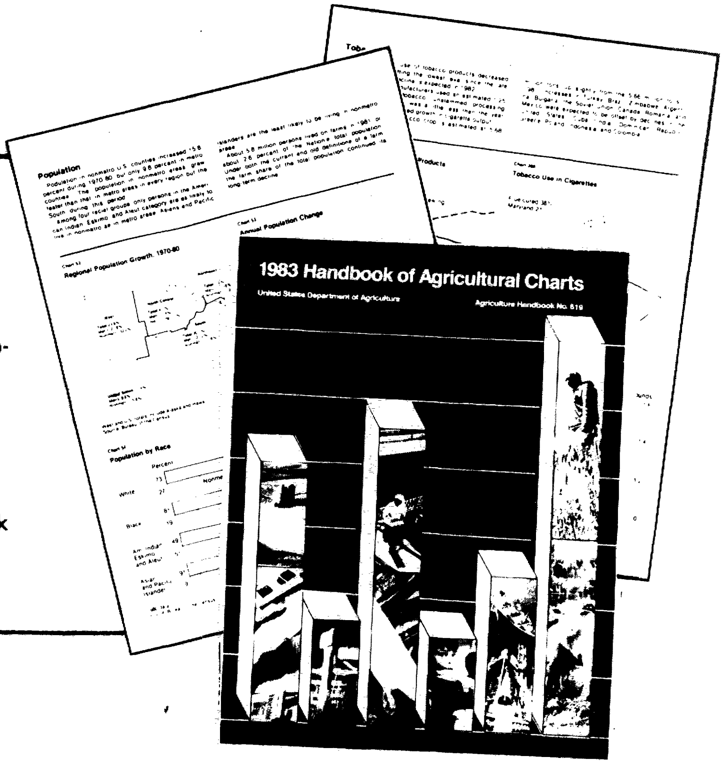

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