Chapter 12
Nonnative Pest Prevention and Control

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Abstract The ability to efficiently produce and market US agricultural goods is contingent on keeping them relatively free of harmful weeds, insects, microbes, and diseases. Despite public and private investments of up to $15.5 billion a year in prevention and control, US agricultural producers still incur at least $98.7 billion in losses and damages to nonnative pests each year. Policies and interventions that prevent or control nonnative pests play a crucial role in safeguarding US agriculture. This chapter surveys a wide array of activities at international, federal, and public–private partnership levels, such as: sanitary and phytosanitary standards, agricultural inspections, off-shore preclearance programs, fees and fines for contaminated shipments, surveillance using sentinel plots, compensation for destroyed crops or livestock, certification based on biosecurity measures, animal disease traceability, disease insurance, compartmentalization, commodity-based trade, and regionalization. Each intervention is assessed according to four criteria: technical, allocative, and dynamic market efficiency; and nonmarket beneficial outcomes. Interventions commonly affect technical, allocative, and dynamic market efficiency, but few affect nonmarket beneficial outcomes. Efforts to address all four criteria are complicated, however, because some interventions improve one criterion at the expense of others.

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Introduction

The ability to efficiently produce and market US agricultural goods is contingent on keeping them relatively free of pests, including harmful weeds, insects, microbes, and diseases (of both plants and animals). Nonnative pests are of particular concern because domestic plants and animals' defenses might not be effective against them. Furthermore, natural predators and other limiting environmental factors might not exist in the United States, or agricultural producers and pest managers might not be trained to identify and control them as effectively as they do for native pests.

Approximately 50,000 nonnative species have been introduced to the United States throughout history (Pimentel et al. 2005). Although most species were introduced intentionally and continue to be beneficial, many were introduced accidentally and have become agricultural pests, including over 500 weed species, 500 insect and mite species, and 20,000 microbe species (Pimentel et al. 2005).[1] Once established in the United States, nonnative pests are rarely eradicated, despite multimillion dollar efforts to do so (Myers et al. 1998). Among the few exceptions are bovine babesiosis,[2] foot-and-mouth disease,[3] and American screwworm (a native pest whose eradication is a sufficiently rare success story to justify its mention) (Bowman 2006; Center for Food Security & Public Health 2008; Meyer and Knudsen 2001). Although these pests have been eradicated from the United States, the threat of their reintroduction persists.

Examples of nonnative pests that have defied nationwide eradication (although not necessarily local or regional eradication) or spread so quickly that eradication was never a feasible option include the emerald ash borer, gypsy moth, golden nematode, cheatgrass, yellow starthistle, wavyleaf basketgrass, citrus canker, soybean rust, karnal bunt, and bovine tuberculosis. Some pests have been successfully eradicated at local or regional scales but not nationwide; examples include tropical spiderwort and the Mexican fruit fly. Even when nationwide eradication is achieved, as with the Mediterranean fruit fly, boll weevil, khapra beetle, highly pathogenic avian influenza and bovine spongiform encephalopathy (BSE), re-emergence is a constant threat.

[1] A species may be beneficial to one sector of society, but harmful to another. The ornamental plant industry, for example, may view an imported species as beneficial, whereas ecologists may view it as potentially invasive and thus harmful. From an economist's perspective, the benefits and costs of all members of society, including the ornamental industry, ecologists and others, should be considered in decisions to import or ban nonnative species.

[2] Bovine babesiosis, or "cattle tick fever," is caused by protozoan parasites of the genus *Babesia*. It is transmitted primarily by the tick species *Rhipicephalus microplus and R. annulatus* (Center for Food Security & Public Health 2008). Introduced to the New World in the sixteenth century through Spanish colonialists' livestock, babesiosis was widespread in the southern United States by the eighteenth century. It was eradicated from the United States in the 1960s, with the exception of a buffer zone along the Texas-Mexico border which remains under quarantine for surveillance purposes (Bram and George 2000; George et al. 2002).

[3] Foot-and-mouth disease is an RNA virus of the genus *Apthovirus* that affects domestic and wild cloven-hoofed species (Meyer and Knudsen 2001). Recognized in Europe since the sixteenth century (Casas Olascoaga 1984), FMD was first recorded in the United States in 1870 (Spear 1982; Sutmoller et al. 2003). Nine major outbreaks occurred in the United States thereafter (Casas Olascoaga 1984), the last of which occurred in California cattle and deer in 1929 (Spear 1982).

Despite investments of up to $1 billion a year in prevention and control by the United States Department of Agriculture Animal and Plant Health Service (USDA APHIS) and at least an additional $14.5 billion by other agencies and individuals, US agricultural producers still incur at least $98.7 billion in losses and damages to nonnative pests each year (Pimentel et al. 2005; USDA APHIS 2009b). This estimate comprises roughly $24 billion in losses and damages from crop weeds, $21 billion from crop pathogens, $19 billion from rats, $14 billion from livestock diseases, $13.9 billion from crop pests, $2.1 billion from forest pests, $2.1 billion from forest pathogens, $1 billion from pasture weeds, $0.8 million from feral pigs, and $0.8 million from starlings (see table 1 in Pimentel et al. 2005). Nonnative pests cause an additional $27 billion or more of broader environmental losses and damages each year, due to such things as lost recreational opportunities, property damage, and power outages (Pimentel et al. 2005).

As the quantities of imported goods and international travel to the United States rise, the task of preventing additional pest incursions becomes increasingly difficult. Furthermore, as the value of US agricultural products sold in international markets grows, pest prevention becomes increasingly important (USDA APHIS 2006). Policies that prevent or control nonnative pests play a crucial role in safeguarding US agriculture's market share in the global economy. The performance of a wide variety of policies that influence nonnative pest prevention and control is assessed below, based on four criteria—technical, allocative, and dynamic market efficiency; and nonmarket beneficial outcomes. The chapter concludes with a discussion of policy gaps and persistent challenges.

Why Are Nonnative Pests a Concern?

Nonnative pests cause significant agricultural production and marketing losses (both domestically and abroad), and trigger large investments in eradication and control programs. When BSE was detected in a Washington State dairy cow in December 2003, 30 trade partners closed their borders to US cattle and beef products (even though the infected cow was imported to the United States from Canada). The US share of world beef exports quickly fell from 8.7 to 1.7% (Marsh et al. 2008), and took over 4 years to recover (Johnson and Stone 2011).

When karnal bunt (caused by the fungal pathogen *Tilletia indica* Mitra) was first detected in US wheat fields in 1996, 37 trade partners refused wheat shipments originating from anywhere within the US (Rush et al. 2005).[4] Although USDA APHIS resolved most wheat export issues within 2 weeks of the first detection, the

[4] Mexico was among the trade partners who banned the import of US wheat, unless it was certified free of karnal bunt or fumigated with methyl bromide (Allen 2002). Ironically, areas of northwest Mexico experienced karnal bunt outbreaks in the late 1970s, long before the first US outbreak. In 1983, the United States banned wheat imports from Mexico to prevent the spread of karnal bunt. Mexico, in turn, restricted imports from the United States after the 1996 outbreak in Arizona. The two countries have since developed a protocol, under the North American Free Trade Agreement, to allow some Mexican wheat to enter the United States and vice versa (Allen 2002).

incidence led to a long-term nationwide karnal bunt surveillance, quarantine, and export certificate program to placate trade partners (Rush et al. 2005; Vocke et al. 2002). A subsequent karnal bunt outbreak in 2001–2002 triggered quarantines in several counties and cost wheat producers $25 million (Rush et al. 2005).

Global transport of goods is the primary mechanism by which nonnative pests enter the United States (di Castri 1989; Mack 2003). Commodities brought in on ships, planes, trains, and trucks account for numerous pest introductions, in part because inspectors are able to examine only a relatively small proportion of inbound shipments. Pests also arrive in international mail and packages, handled by either the United States Postal Service or private-sector delivery companies. As the volume, frequency, speed, and diversity of imported cargo and travelers to the United States grow, it becomes increasingly difficult to prevent and detect agricultural pest incursions (Ruiz and Carlton 2003).

Global agricultural trade increased 50% between 2001 and 2005, two times the growth rate experienced in the previous decade (Gehlhar et al. 2007). Between 1996 and 2003, agricultural imports to the United States grew nearly twice as fast as agricultural exports from the United States (Jerardo 2004). In 2008, a record $70 billion in agricultural products was imported to the United States (USDA ERS 2009a). Consumption of imported food in the United States increased from 215 lb per person per year in 1989 to 348 lb in 2008, a 62% increase (USDA ERS 2010). Although trade expansion does not conclusively increase the total cost of nonnative pests (Costello and McAusland 2003), it does increase US agriculture's exposure to them. More effective prevention and management tools are needed to maintain current levels of agricultural productivity and marketability in the face of expanding international trade.

International travel is an important mechanism for the introduction of nonnative pests. Fifty-eight million people visited the United States in 2008, a 25% increase from 2004 (UNWTO 2010). Thirty-two million of these visitors arrived by air, 25 million by road, and 0.5 million by sea. Proportions of visitors from various geographic regions were as follows: Canada (32%), Mexico (24%), Europe (23%), East Asia and the Pacific (11%), South or Central America and the Caribbean (8%), South Asia (1%), Africa (0.5%), and the Middle East (0.5%) (UNWTO 2010). Visitors from Canada and Mexico, or other countries with similar climates and ecosystems, might accidentally or intentionally introduce pests that are well adapted for survival in the United States. Visitors from regions with less-similar climates and ecosystems might introduce pests that are not as well-adapted to the United States, but are not well known and are therefore more difficult to detect, identify, and control. These pests might also be highly virulent to indigenous species, which are unlikely to have effective defenses against such foreign invaders.

US residents who travel internationally also have the potential to introduce nonnative agricultural pests upon their return home. US residents took 73 million trips abroad in 2008 (UNWTO 2010). Proportions of these visits to various regions were as follows: Mexico (25%), Europe (25%), South or Central America and the Caribbean (19%), Canada (17%), East Asia and the Pacific (11%), South Asia (1%), Africa (1%), and the Middle East (1%) (UNWTO 2010). Agriculture specialists with US Customs and Border Protection (CBP), and officers with USDA APHIS's Smuggling, Interdiction and Trade Compliance (SITC) Program, search baggage at ports of entry and confiscate agricultural items, but the volume of passengers is sufficiently large that some nonnative plant and animal pests enter the nation undetected. Detection is complicated by pests that can be carried inadvertently on clothing (e.g., foot-and-mouth disease virus in soil on the soles of shoes), or shipped intentionally to the United States through international mail (e.g., classical swine fever virus in smoked or salt-cured pork products). New pest incursions are inevitable, and the growing diversity and volume of potential vectors makes them increasingly likely and frequent.

The potential economic consequences of nonnative pest incursions are also increasing, due to the rising value of US agricultural exports, and growing concern among consumers (both domestic and international) and trade partners about sanitary and phytosanitary (SPS) issues. Nearly one-quarter of US agricultural products (by volume), valued at $82 billion or 13% of the nation's $635 billion food and fiber industry, were exported in 2008 (USDA ERS 2009a). The United States enjoyed record-setting export shipments from 2004 to 2008 because of GDP growth in emerging markets (Gehlhar et al. 2007; Shane et al. 2008). Nonnative agricultural pests, brought into the United States through imported goods and international travel, are a significant threat to the nation's growing share in agricultural export markets.

Numerous public agencies and private organizations engage in the prevention, control, and management of nonnative pest outbreaks in the United States. The remaining sections of this chapter discuss why policy interventions are needed; review current and emerging policies related to nonnative agricultural pests; assess their impacts according to four performance measures; and identify remaining gaps and challenges.

Why Is Government Intervention Necessary?

Externalities, public goods, and imperfect information prevent agricultural markets from achieving socially efficient levels of pest prevention and control. Government intervention can potentially improve efficiency by correcting or mitigating these forms of market failure. Before reviewing individual government interventions and assessing how well they perform, we first need to understand the market failures they attempt to address.

Externalities

The invasive nature of nonnative pests creates the potential for individual production and trade decisions to impose external costs and benefits on others. If an individual producer considers only the private benefits and costs from exporting an agricultural product that potentially harbors an invasive pest, they risk imposing external costs on their trade partners, and causing more pest-related damage than is socially optimal. Similarly, if an industry considers only their private benefits and costs of importing a nonnative species (e.g., a new ornamental plant), and ignores potential ecological implications of their decision (e.g., introduction of an invasive plant species or an insect or microorganism transported in the plant's soil), more invasive species will be introduced than is socially optimal. Likewise, if individuals weigh only their private benefits and costs of controlling pests, and ignore external benefits to their neighbors or trade partners, they will choose a socially inefficient level of control, usually too little.

The concept of externalities may seem more complex when individuals are making pest-related decisions based on imperfect information. Decision-making under uncertainty, after all, can result in unanticipated costs or benefits for both the individual decision-maker and third parties. Externalities only occur, though, if the individual makes their decision without considering the expected benefits and costs (i.e., probability-weighted benefits and costs) their decision may impose on others. If instead the individual considers these expected benefits and costs, but misestimates their magnitude due to imperfect information, the resulting decision does not technically cause externalities. As long as the individual made their decision based on the best-available information (or, more precisely, the socially efficient level of information) about expected social benefits and costs, their decision is socially efficient. Any difference between expected and actual (or realized) social benefits or costs should be attributed to imperfect information rather than externalities.

Government intervention in agricultural markets, through regulations, taxes, subsidies, bonds, or tradable permits, helps align private benefits and costs with social benefits and costs, and reduces market failures stemming from externalities. Regulation is the primary tool used in the United States, and around the world, to combat externalities that would otherwise lead to an overabundance of nonnative agricultural pests. Specific examples of regulatory approaches, and a discussion of their efficiency, appear later in the chapter; for now, it is sufficient to simply understand that externalities exist and that government interventions have been designed, in part, to counteract them.

Public Goods

Prevention and control of nonnative pests exhibit characteristics of a pure public good, another common cause of market failure. Economics defines a "pure public good" as a good that is both "non-rival" (i.e., the same unit of a good can be enjoyed by many people) and "non-excludable" (i.e., it is difficult to prevent people from enjoying the good, even if they have not paid for it). Free markets tend to underprovide public goods relative to their socially optimal levels because individuals have an incentive to "free-ride" (i.e., wait for others to provide the good because they know they will be able to enjoy it for free). When many people engage in free-riding, it collectively results in too little of a public good being provided.

In some cases, even if a person's private benefit from producing a good outweighs the cost they sometimes choose not to produce it. This is because their net benefit will be even greater if they wait until someone else produces it, and then enjoy the good for free (which is only possible because the good is non-rival and non-excludable). Imagine several cattle ranchers, for example, who share a common grazing allotment invaded by yellow starthistle, an unpalatable nonnative weed (DiTomaso et al. 2006). Suppose a single application of a common herbicide each year could control the weed, and that each rancher would benefit sufficiently from the herbicide to justify paying for it themselves. Individuals might still be tempted to free-ride, i.e., wait for one of their fellow ranchers to pay for the herbicide application, and then enjoy the resulting forage benefits for free. If every rancher attempts to free-ride, however, the herbicide will never be applied, and the individual ranchers will be worse off than if they had invested in the herbicide themselves.

One means to overcome this market failure, and achieve a level of herbicide application that is best for all of the ranchers, is to create a legally binding cost-share agreement between them that prevents free-riding. Grazing associations are one example of such an agreement. They have been used for decades to coordinate ranchers who share grazing allotments and encourage them to invest in range improvement projects (Culhane 1981, p. 251). The Hector Grazing Association of the Finger Lakes National Forest in New York, for example, secures grazing fee reductions from the US Forest Service for association members who help manage invasive species by mowing ragweed and goldenrod (United States Forest Service 2005).

For some public goods, the cost of providing the good is sufficiently high that no individual stakeholder's private benefit outweighs that cost, so no individual can justify producing it. Because the good is non-rival though, many people would benefit from having it, and the "social benefit" of the good (i.e., the sum of benefits across all individual members of society) would outweigh the cost. If provision of the good is left to individuals, the good will never be provided; not because people are free-riding, but because their personal benefit does not outweigh the cost. Society as a whole would be better off if the good were provided though. Collective action or government intervention is needed to overcome this type of market failure.

Inspection services at US ports of entry provide an example of this form of the public goods problem. Inspection services are non-rival and non-excludable; they benefit thousands of US agricultural producers and consumers who cannot be prevented from enjoying the benefits of inspection for free once the service has been provided. Inspection services are also sufficiently costly to provide that no individual's benefit outweighs the cost. As a result, no individual can justify providing inspection services, even though the social benefit might exceed the cost (i.e., society as a whole might be better off with inspection services).

One means of overcoming this version of the public goods problem is for the government to impose a user fee or tax on society to raise sufficient funds to pay for inspection services. Ideally, the fee or tax would only be imposed on those who benefit directly from inspection services, such as sellers and buyers of imported goods, and domestic producers whose goods need to be inspected to gain access to international markets. APHIS and CBP collect Agricultural Quarantine and Inspection user fees from the following clients to help cover the cost of inspection services: international passengers; incoming commercial vessels, trucks, railroad cars, and aircraft; live-animal importers; and domestic producers in need of export certificates (Code of Federal Regulations 7 CFR § 354.3 and 9 CFR § 130). Taxpayer dollars fund the remainder of the agencies' budgets.

Imperfect Information

Imperfect information is not technically a market failure, but it makes the prevention and control of nonnative pests more complicated and costly. Imagine how much easier it would be to prevent pest incursions if we knew exactly which shipments were contaminated. Imagine how much more effective our control efforts would be if we knew the exact distance, direction, and mechanism of a nonnative pest's spread. Consider how much more difficult it is, in contrast, to prevent and control pest incursions when information is imperfect. Although risk assessors use probabilistic approaches to mitigate information gaps, and may feel relatively confident about their policy recommendations, such analyses become increasingly difficult as the degree of uncertainty and imperfect information worsens.

Imperfect information makes it more challenging, for example, to determine whether additional resources should be allocated to prevention of avian influenza in domestic birds. Avian influenza viruses are native to water birds throughout the world, including the United States, but the highly pathogenic strain that emerged in 1997 (H5N1) originated in Hong Kong (Webby and Webster 2001). Many pieces of the avian influenza puzzle are uncertain, including the proportion of wild birds carrying the virus; how often they interact with domestic birds; the likelihood of disease transmission when they interact; and the probability of the strain being highly pathogenic.

Millions of dollars could be appropriately invested to reduce the probability of domestic birds contracting avian influenza from wild birds, or to intercept a larger proportion of goods smuggled from countries where this disease is prevalent. An outbreak could nevertheless occur due to imperfect information about the nature or timing of interactions and transmission at the domestic–wildlife interface, or a single undetected shipment of contaminated goods. This example highlights that, although good decisions can be made under uncertainty, the possibility of a bad outcome almost always remains. Good decisions can reduce the probability of a bad outcome, but they rarely eliminate it entirely.

In the absence of perfect information, a highly precautionary approach to pest prevention and control may be tempting. The government could, for example, require all poultry to be confined indoors as a means of reducing the probability of interaction with wild birds. Alternatively, every shipment of imported products originating from a country affected by highly pathogenic avian influenza could be inspected. These approaches ignore, however, the cost of constructing adequate facilities, enforcing regulations, and conducting inspections. These costs might exceed the benefits such activities would generate.

Before making pest prevention and control decisions, managers and policymakers should always weigh the costs and benefits of alternative levels and strategies (Kaiser 2006). Costs and benefits are more difficult to quantify, however, when uncertainty exists about underlying levels of risk or the extent to which alternative strategies reduce risk. Additional information could be gathered to reduce uncertainty, but this too is often costly, and should only be done if the benefit of having more complete information outweighs the cost of obtaining it.

Even if markets were free of externalities, public goods, and imperfect information, or if government interventions perfectly corrected these sources of market failure, socially optimal levels of pest prevention and control still might not be achieved. Although technical and allocative efficiency might be achieved, other goals, such as dynamic efficiency (e.g., innovation and ability to adapt to change over time) and nonmarket beneficial outcomes (e.g., equity, social justice, environmental health, and animal welfare) might not be achieved. Government interventions might still be necessary in such cases to reach society's desired balance between traditional measures of efficiency and other social goals.

How Is Government Intervening?

Extensive regulatory frameworks exist at both the international and national level to mitigate market failures in the prevention and control of nonnative agricultural pests. Major laws, regulatory agencies, and public–private partnerships that address nonnative agricultural pests are reviewed next. This sets the stage for subsequent discussions of how existing policies and programs improve efficiency, and what gaps and challenges remain.

International Programs

The World Trade Organization's Agreement on Sanitary and Phytosanitary Measures (henceforth the WTO's SPS Agreement) is the primary tool for ensuring that SPS measures are science-based, as opposed to unjustified barriers to trade. Enacted in 1995, the SPS Agreement seeks to balance trade liberalization with individual countries' sovereign right to ensure food safety for its citizens and prevent the spread of agricultural and ecological pests (WTO 2000). It promotes harmonization of SPS standards across countries and enables countries to challenge each other's SPS measures.

Responsibility for setting animal health standards lies with the World Organization for Animal Health, which was established in 1924 as the Office International des Epizooties but renamed in 2003 (although it is still known today as the OIE).

Roughly 178 countries are members of the OIE (World Organization of Animal Health 2012). The International Plant Protection Convention (IPPC; first adopted in 1951 by the Food and Agriculture Organization of the United Nations) is responsible for developing plant health standards, which are known officially as International Standards for Phytosanitary Measures (ISPMs). Roughly 177 countries are signatories of the IPPC (2010).

Member countries of the OIE and IPPC set SPS standards, monitor the spread and control of pests around the world, oversee dispute resolution procedures, and facilitate information exchange. Both organizations provide online databases and email notification services to promote timely and transparent reporting of global pest outbreaks. OIE maintains the World Animal Health Information Database, while the IPPC provides links on their homepage to pest reports, ISPMs, and country-specific legislation.

The OIE and IPPC support regional organizations, which encourage neighboring countries to share information, improve institutional capacity, and coordinate surveillance and control activities. Regional organizations are the most common means for individual member countries to communicate with the OIE and IPPC, although members are responsible for reporting pertinent information regardless of their Regional Plant Protection Organization's (RPPO) level of engagement.

The OIE has five "Regional Representations," one each in Africa, the Americas, Asia and the Pacific, Eastern Europe, and the Middle East. The United States is a member of the Regional Representation for the Americas, which includes 29 countries and focuses on three strategic areas: strengthening the capacity of national veterinary services, strengthening national health information systems, and harmonizing animal health standards (OIE RCA 2004).

The IPPC has ten RPPOs. The United States is a member of the North American Plant Protection Organization (NAPPO), along with Canada and Mexico. Several RPPOs across North, Central, and South America (including NAPPO) formed a coalition known as the "Regional Plant Protection Organizations of the Americas," which coordinates plant protection efforts across larger geopolitical scales (Regional Plant Protection Organization of the Americas 1998).

OIE's Regional Representation for the Americas, in contrast, sees a need to coordinate animal protection efforts at smaller geopolitical scales. It is otherwise difficult to meet the needs and interests of its diverse membership of 29 countries. Trade-offs clearly exist between achieving meaningful levels of coordination at the regional scale and identifying sufficiently focused agendas. Neither OIE nor IPPC's regional committees have found a completely satisfactory balance yet, but IPPC has attempted to address this organization challenge by establishing multiple levels of coordination that facilitate communication at several scales.

Effective communication and mutual trust amongst trade partners' national plant and animal health agencies are essential for preventing the spread of agriculture pests via international trade (Romano and Thornsbury 2006). Countries may agree on a set of risk management practices required for an agricultural product to be imported (e.g., fumigation at harvest, or cold treatment during transit), but such agreements are only meaningful if the importing country trusts the exporting country to implement those practices. Signatories to the IPPC are bound by its bylaws and required to abide by ISPMs, but results of worldwide surveys by the U.S. Department of State raise concerns about the willingness or ability of trade partners to enforce SPS standards (Reaser et al. 2003). A State Department survey in 1999 found "Few countries considered [nonnative pests] a high priority, had coordinated policies and plans in place specifically aimed at minimizing the problem, and were dedicating substantial resources to prevent and control the spread" (Reaser et al. 2003).

Developing countries interested in making invasive species management a national priority (if only to gain access to international markets) often lack the scientific, technological, and financial resources to do so (Reaser et al. 2003). In recognition of this, the IPPC has devoted more resources to technical capacity building in recent years. International visits and collaborative research on risk management techniques are other means by which the IPPC's member nations can attempt to strengthen trade partners' engagement in pest management, and build trust between countries' plant and animal health officials. One successful example is the placement of APHIS personnel abroad, where they work side-by-side with host countries' agricultural inspectors to validate proposed pest treatments, provide professional training, and verify correct implementation of mitigation measures. More investments abroad, ideally by benefactors of improved pest prevention and control, may still be necessary to increase less-wealthy trade partners' willingness and ability to manage pests and meet SPS standards.

Both the OIE and IPPC have voluntary evaluation programs to help countries assess their ability to meet SPS standards. Seventy-five countries have completed the OIE's Performance of Veterinary Services evaluation; an equal number have completed the IPPC's Phytosanitary Capacity Evaluation (WTO STDF 2009). Such evaluations help countries identify gaps and weaknesses in their national plant and animal health systems and develop priorities and strategies for improvement (WTO STDF 2009). They also enhance participating governments' understanding and acceptance of SPS standards and the WTO's awareness of constraints that prevent developing countries from meeting SPS standards (WTO STDF 2009). In the long run, programs like these will empower developing countries to better manage existing agricultural pests, implement risk management practices that satisfy SPS standards, and thereby reduce the spread of pests through international trade.

Federal Programs

The United States faces significant coordination challenges not only with trade partners, but within its own borders amongst the numerous federal agencies that address nonnative pest issues (Reaser et al. 2003). Three laws define the Federal government's role in preventing and controlling nonnative pests: the Plant Protection Act of 2000, the Animal Health Protection Act, and the Federal Seed Act (USDA ERS 2009b). These Acts give numerous federal agencies authority to implement a wide variety of tools to prevent and control nonnative pest outbreaks in the United States (USDA ERS 2009b). Agencies with primary responsibility for pest prevention and control are discussed briefly.

The USDA's Animal and Plant Health Inspection Service (USDA APHIS) has primary responsibility for protecting agriculture from nonnative pests. Four programs within APHIS address this objective: Veterinary Services (VS), Plant Protection and Quarantine (PPQ), Biotechnology Regulation Services (BRS), and International Services (IS) (USDA ERS 2009b). These programs implement a variety of tools authorized by federal legislation, including monitoring, surveillance, training, testing, quarantine, treatment, management, eradication, and compensation to agricultural producers for crops or animals destroyed for pest management purposes (Magarey et al. 2009; USDA ERS 2009b). They also analyze SPS risks associated with the import and export of agricultural products (Magarey et al. 2009; Cavey 2003). Much of the risk analysis work is conducted at APHIS Headquarters in Riverdale, Maryland and the APHIS PPQ Center for Plant Health Science and Technology in Raleigh, North Carolina. After risks are analyzed, either qualitatively or quantitatively (Hayes 2003), APHIS decides which products should be allowed into the United States, from what regions of the world, and under what risk management protocols.

As required by the SPS Agreement, APHIS uses risk analyses as the basis for scientific justification of SPS measures that protect US agriculture from nonnative pests. Many SPS issues are resolved informally through bilateral negotiations with trade partners. APHIS's on-going international outreach efforts facilitate such negotiations, indirectly, by: (1) improving trade partners' understanding of SPS risks, and thus perhaps their willingness to accept SPS standards, and (2) strengthening trade partners' capacity to manage agricultural pests and diseases, and thus potentially reducing US agriculture's exposure to nonnative pests (Magarey et al. 2009; Reaser et al. 2003; USDA APHIS 2009a).

Agricultural inspections at US ports of entry and border crossings are another vital tool for preventing nonnative pest invasions. Historically, APHIS was responsible for conducting these inspections; however, the Department of Homeland Security's Customs and Border Protection (USDHS CBP) assumed responsibility in 2003 in the wake of terrorist attacks on the United States in 2001. CBP collaborates with APHIS to fulfill agricultural inspection tasks, but their new partnership has not been easy. A joint task force review in 2007 revealed concern among stakeholders and APHIS employees that CBP had not sufficiently incorporated agriculture into their primary mission, which is to prevent terrorists, terrorist weapons, illicit drugs, and illegal immigrants from entering the United States (USDHS CBP and USDA APHIS 2007).

Recommendations for raising agriculture's profile within CBP's mission included more effective joint planning efforts between CBP and APHIS, and an increase in the number and level of staff that support the agricultural inspection mission (USDHS CBP and USDA APHIS 2007). CBP also indicated a need for more agriculture specialists in their 2006 performance and accountability report, particularly at ports of entry and border stations (USDHS CBP 2006). They have since increased the number of agricultural inspectors from 1,560 to 2,360; they have also expanded the agricultural canine program from 75 to 114 teams, enhanced the level to which agricultural inspectors can be promoted, and developed new pest detection modules for continuing education of inspectors (USDHS CBP 2011). Performance is thought to have improved as a result, although some deficiencies certainly remain (Harriger 2011; USDHS CBP 2009, 2011, 2012).

Exclusion is another important concept in the prevention of nonnative pest outbreaks. Exclusion refers to the detection and elimination of pests before they reach US shores. APHIS directs several programs that help identify pests in other countries and prevent them from being exported to the United States. OPIP (Offshore Pest Information Program) and EPICA (Exotic Pest Information Collection and Analysis) were developed separately, but eventually merged, to systematically gather, assess, and synthesize information about pests and diseases in other countries, and communicate it to APHIS personnel and partners through electronic newsletters and searchable databases (USDA APHIS 2010a, b). This flow of information about pests and recent outbreaks in other countries allows APHIS personnel to anticipate potential pest risks before they reach US shores, initiate preparedness planning, and adjust inspection procedures when risks are deemed sufficiently high to justify regulatory action.

APHIS also develops, implements, and maintains offshore agricultural commodity preclearance programs at dozens of locations around the world (USDA APHIS 2007). The Commodity Preclearance Program, for example, inspects, treats, and certifies agricultural goods within their country of origin to reduce the risk of pests reaching the United States (USDA APHIS 2002). Qualified APHIS personnel supervise preclearance inspections and treatments on-site, and inspectors conduct integrity checks at US ports to ensure compliance (USDA APHIS 2007). An industry wishing to establish a preclearance program must work closely with their home country's plant protection service and APHIS to propose, develop, test, and maintain adequate facilities for the inspection, treatment, packaging and certification of agricultural commodities (USDA APHIS 2002). Preclearance programs in Chile provide an example of the coordination and technical complexity involved in operating a preclearance facility (Silagyi 2010).

In addition to preclearance programs, APHIS also works in other countries to help trade partners manage pests that pose a serious threat to US agriculture. APHIS manages a center in northern Mexico, for example, that releases sterile Mexican fruit flies (*Anastrepha ludens*) to suppress (and perhaps someday eradicate) this pest along the Texas-Mexico border (USDA APHIS 2010c). This effort directly benefits eradication efforts in the Lower Rio Grande Valley of Texas, but similar efforts are also underway in more distant locations. APHIS tracks the distribution of tropical bont tick, for example, in the Caribbean and provides assistance to countries trying to eradicate it (Bram and George 2000). APHIS hopes to prevent this nonnative tick, which is a vector of *Cowdria ruminantium*, the causative agent of a deadly ruminant disease known as heartwater, from reaching southern Florida and its livestock populations (USDA APHIS 2010c). Offshore investments like these are representative of APHIS's efforts to prevent nonnative pest outbreaks by detecting and eradicating them before they reach the United States.

Other USDA programs and divisions as well as other federal agencies provide valuable data, research, training, and financial support, which help protect US agriculture from nonnative pests. USDA's Agricultural Research Service (USDA ARS), for example, manages national research programs on animal health, plant diseases, crop protection, and quarantine (USDA ARS 2010). These programs address a variety of nonnative pest issues, including exotic citrus diseases such as citrus tristeza virus; the epidemiology of *Xylella fastidiosa* (which causes Pierce's disease in grapes); biological control agents for yellow starthistle; quarantine services for emerald ash borer; management of invasive beetles in horticultural, turf, and nursery crops; improved control of invasive fruit flies and Asian citrus psyllid; control of zoonotic avian viruses and foreign diseases of swine; vector competence of North American mosquitoes for Rift Valley Fever virus; immunity enhancement against foot-and-mouth disease; and effective alternatives to methyl bromide, a common soil and postharvest treatment phased out under the Montreal Protocol and the US Clean Air Act (Schneider et al. 2003; USDA ARS 2010).

USDA ARS research provides information critical to APHIS's risk analyses, rule-making processes, and prevention and control policies. APHIS scientists, in many cases, work side-by-side with ARS personnel to develop new SPS treatments. The APHIS PPQ Center for Plant Health Science and Technology is actively involved, for example, in developing methyl bromide alternatives (USDA APHIS 2011a).

So many federal agencies share responsibility for the prevention and control of invasive species, or otherwise influence the introduction and distribution of invasive species, that an official means of coordination is necessary. The National Invasive Species Council (NISC) was created in 1999 to develop a coordinated network among federal agencies to document, evaluate, and monitor invasive species' impacts (Reaser et al. 2003). The NISC was also tasked with developing recommendations for international cooperation; encouraging planning and action at regional, state, tribal, and local levels; and preparing a National Invasive Species Management Plan (The White House 1999). Secretaries and Administrators from 13 federal departments and agencies sit on the Council and the Secretaries of the Interior, Agriculture, and Commerce serve as cochairs.

The NISC's 2008–2012 National Invasive Species Management Plan defines five long-term strategic goals (NISC 2008). The objectives and tasks associated with these goals reveal a wide array of challenges that federal agencies face in the battle against nonnative pests. Example objectives from the 2008 to 2012 National Invasive Species Management Plan include improving and expanding domestic and international risk analysis processes; developing fair and practical screening processes to evaluate species moving through trade; incorporating invasive species issues into free trade agreements; improving US participation in the Global Invasive Species Information Network and the Inter-American Biodiversity Information Network; integrating agency data sets to improve invasive species threat assessment; improving economic modeling of invasive species; developing a process to identify high-priority invasive species; identifying mechanisms to fund rapid response efforts; and creating citizen-based networks to monitor new invasive species (NISC 2008). These objectives highlight the diverse set of activities (from prevention to management) that must be coordinated both within and across multiple scales (from local to international). Coordination is essential for efficient prevention and control of nonnative pests.

Public–Private Partnerships

Public–private partnerships provide a valuable link between government agencies that regulate activities capable of spreading nonnative pests, and stakeholders who engage in such activities or are affected by nonnative pests. These partnerships help improve government agencies' ability to identify new pest-related issues; gather data about emerging or on-going pest outbreaks; develop and test innovative management tools; design pest prevention and control policies that are sensitive to stakeholders' concerns; convey educational materials to appropriate audiences; and leverage funds for research, outreach, and program implementation. More public–private partnerships for nonnative pest prevention and control exist than can be covered in one chapter. A few examples are given, however, to provide a sense of their composition, goals, and accomplishments.

USDA APHIS partners with universities, industry groups, state agencies, and other natural resource protection organizations to manage the Cooperative Agricultural Pest Survey (CAPS). CAPS is a national program that surveys, identifies, monitors, and prioritizes over 400 plant pests (USDA APHIS 2005a). Pest surveyors collect climatic, environmental and pest-specific data, upload them to state databases, and then transfer them to the National Agricultural Pest Information System. CAPS focuses both on pests already present in the United States and potential threats that have not yet arrived. Data regarding existing pest incursions help APHIS determine which locations require quarantine and which can be declared pest-free (a declaration that has important trade implications). Data regarding potential invaders informs emergency preparedness and response planners and off-shore pest exclusion programs (USDA APHIS 2005a).

CAPS sponsored the development of NAPPFAST, a computer model that uses climatic and environmental data to predict when and where a pest incursion might occur in the United States (Magarey et al. 2007). CAPS uses this model, as well as input from the National CAPS Committee, National Plant Board, APHIS PPQ, and industry groups, to identify plant pest priorities each year (Cooperative Agricultural Pest Survey 2009). Although CAPS provides a means for state and federal agencies to coordinate pest surveillance and monitoring efforts, the extent to which private industry is engaged (aside from providing access to agricultural fields for surveillance purposes) is less clear. Magarey et al. (2009) suggest more incentives are needed for industry to share pest data with state and federal agencies. This would help reduce the cost of data collection, which is an important barrier to more effective pest surveillance.

USDA also collaborated with the United Central Soybean Board and state extension service offices to develop a national monitoring system for soybean rust, a fungus introduced to the United States in 2004 by the winds of Hurricane Ivan (Aultman et al. 2010). The soybean rust monitoring network comprises several hundred sentinel soybean plots around the country, which state extension personnel manage exclusively for the purpose of detecting rust. Leaf samples are sent regularly to land grant university's labs for testing. Test results are made available to the public through the IPM PIPE website, which publishes a weekly map of confirmed rust cases. Soybean producers can sign up for automatic email alerts when rust is detected in their region (Aultman et al. 2010). Researchers have also developed a model to predict the spread of rust based on atmospheric forecasts for the upcoming week (Isard et al. 2007). With up-to-date outbreak data and weekly forecasts, producers have more complete information with which to choose preventive, reactive, or no action to protect their fields.

Because soybean rust has generated smaller losses than originally predicted, the USDA and Soybean Board have reconsidered the sentinel plot program's scale. Partnering with scientists at the University of Minnesota, they are working to determine the economically optimal number and location of sentinel plots (Aultman et al. 2010). This research provides a good example of innovative pest management tools that arise from effective public–private partnerships. In this case, technical experts generated information directly applicable to producers' pest management decisions and conveyed it to producers in a highly accessible and timely manner. APHIS has similar public–private partnerships with many other stakeholders and research universities with whom they work collaboratively to develop effective pest monitoring and control strategies.

USDA APHIS also partners with private industry to address animal disease issues. They work with livestock producers and state animal health officials, for example, to collect data for the National Animal Health Monitoring System (NAHMS), a nationwide survey of animal diseases and health management practices (USDA APHIS 2010d). As described by Bullis (1977), they partner with the poultry industry and state animal health agencies to manage the National Poultry Improvement Plan (NPIP). NPIP establishes disease evaluation standards for poultry breeding stock and hatchery products, and administers a certification system that facilitates trade (Code of Federal Regulations 9 CFR § 145–147; Rhorer 2004). Originally created in 1935 to address pullorum disease (caused by *Salmonella pullorum*), the NPIP now monitors US flocks for H5 and H7 low pathogenic avian influenza (AI) viruses, and certifies that operations supplying poultry products for international shipments are free of avian influenza (Bullis 1977; Hall 2004).

Unlike other pests mentioned in this chapter, low pathogenic AI is indigenous to the United States. It has sufficiently important implications though for marketing of US poultry products, both domestically and internationally, to justify a brief discussion. Each year, a small proportion of US poultry becomes infected with low pathogenic AI, along with 10% of migratory water birds (Hall 2004). Trade partners are concerned about the ability of low pathogenic AI to mutate to highly pathogenic forms. Such mutation was first observed in the United States during an outbreak in

Pennsylvania in 1983 (Hall 2004). Similar mutations have occurred in other countries as well, including Mexico, Italy, France, Denmark, the United Kingdom, South Korea, and Japan (Hall 2004; World Organization for Animal Health 2010).

Backyard or free-range poultry flocks pose a serious challenge to AI prevention efforts in the United States because they are at greater risk of contracting diseases from wild birds than are confined flocks typical of most commercial operations (Hall 2004). Fortunately, commercial operations with good biosecurity practices have a low probability of contracting diseases from neighboring backyard flocks (Garber et al. 2007). OIE's recent adoption of a concept known as compartmentalization (i.e., biosecurity practices that allow commercial poultry to be considered separate from backyard flocks for purposes of trade) has further reduced the extent to which disease outbreaks among backyard flocks disrupt commercial trade (Garber et al. 2007).

NPIP is an excellent example of a highly organized campaign by private industry, in partnership with federal and state agencies, to improve animal disease management for the purpose of enhancing product marketability. The organization's successful control of pullorum disease and fowl typhoid (*Salmonella gallinarum*) provides insights relevant not only to current poultry diseases (e.g., low pathogenic AI and *Salmonella enteritidis*), but to other agricultural industries as well.

The National Pork Board, following NPIP's example, has engaged in a similar partnership with USDA APHIS for over a decade to develop a voluntary Trichinae Certification Program (TCP) (Code of Federal Regulations 9 CFR § 149; Pyburn 2003). *Trichinella* spp. are parasitic roundworms that can be transmitted from swine to humans through consumption of infected meat that is not properly frozen or prepared (Centers for Disease Control 2008). Some trade partners require all fresh pork imported from the United States to be tested for *Trichinae* spp. Such testing is sufficiently costly that it makes the market economically inaccessible to US pork producers. Producers are working to gain access to these markets by proving that the TCP provides equivalent safety assurances at lower cost (Rogers and Brownlee 2007). TCP certifies that participating producers implement best management practices to minimize the risk of *Trichinella* spp., and that pigs from certified operations are processed in separate facilities from pigs produced in uncertified operations (USDA APHIS 2008). Certification, based on the adoption of best management practices and separate processing facilities, is in some sense a form of compartmentalization. Certification distinguishes low-risk operations from high-risk operations and, therefore, qualifies them for different testing requirements and less-severe trade restrictions during an outbreak.

It is too soon to determine whether TCP will create significant new export opportunities for US pork producers, but some experts believe this farm-level approach to food safety is superior to the traditional approach of testing individual animals at slaughter (Pyburn 2003). If this is shown to be true, farm-level certification programs might be a practical means to standardize animal health practices in the beef industry as well. Standardization is more challenging in the beef industry because operations tend to be more heterogeneous in type, size, and location. The beef industry is also less integrated, both horizontally and vertically, than the pork and poultry industries. It has multiple producer organizations that do not share the same opinion on issues such as animal identification and marketing strategies. Given the beef industry's disparate and disaggregated nature, it is more difficult to gain the necessary momentum for industry-led initiatives. Programs directed at individual producers, such as certification, might be successful, particularly if they are flexible enough to accommodate highly diverse beef operations.

USDA APHIS and state agencies also partner directly with agricultural producers by offering them financial incentives to invest in pest prevention and control. APHIS and state agencies provide cost-sharing to producers who adopt best management practices for the prevention and control of high-profile pests. Cattle producers in the Greater Yellowstone Area, for example, receive free testing and adult-booster vaccination for bovine brucellosis, which is indigenous to the United States (Peck 2010). APHIS has also compensated some producers in the past for crops or livestock destroyed during pest eradication campaigns (e.g., citrus canker, karnal bunt, plum pox, exotic Newcastle disease). Compensation encourages producers to report pest outbreaks to government officials, who can then implement appropriate control techniques more quickly. In the absence of compensation, producers might attempt to sell infected crops or livestock, or manage outbreaks on their own, to avoid uncompensated destruction. Given the ability of many nonnative pests to spread quickly, illicit or elusive behavior by producers might be more costly to the government than compensation.

Federal agencies other than USDA APHIS also engage in public–private partnerships to prevent and control nonnative pests. The U.S. Geological Survey's Biological Informatics Office, for example, partnered with the World Conservation Union's Invasive Species Specialist Group, universities, nonprofit organizations, and other federal agencies to create the Invasive Species Information Node (ISIN) (National Biological Information Infrastructure 2008). ISIN provides a single web portal through which numerous sources of information about nonnative pests can be accessed. It is intended to serve as an early detection and rapid response information system for invasive species control in the United States. When fully functional, it will house: invasive species identification tools, such as the Global Invasive Species Database; predictive models of vulnerable habitat and future spread of invasive species; tools for reporting and mapping invasive species occurrences; automated delivery of early detection information to managers and decision-makers; a search interface that accesses multiple invasive species databases; and data collection standards to promote interoperable databases (National Biological Information Infrastructure 2010). When fully developed, ISIN will facilitate information exchange and help coordinate invasive species detection and control nationwide.

The NISC also collaborates with private industry to identify high-priority and emerging issues that require a coordinated response from multiple federal agencies. More specifically, NISC seeks input from the Invasive Species Advisory Committee (ISAC), a board comprising 32 nonfederal experts and stakeholders who represent state, tribal, local, and private concerns (ISAC 2006). ISAC's member list in recent years included representatives from a diversity of organizations, such as the

American Seed Trade Association, Michigan Nursery and Landscape Association, Chamber of Shipping of America, Pet Industry Joint Advisory Council, Defenders of Wildlife, and producers from the crop, livestock, and aquaculture industries. The Committee also included numerous technical experts from universities, and state agricultural and environmental agencies (ISAC 2010). The Advisory Committee meets twice annually to discuss emerging challenges and advances in invasive species management. They also provide input for the National Invasive Species Management Plan, and produce guidance documents for federal agencies (NISC 2008). Assuming ISAC is sufficiently representative and influential, it affords stakeholders a single efficient avenue to influence the invasive species management activities of 13 federal departments and agencies.

Numerous other programs, partnerships, tools, and activities exist to enhance the prevention and control of nonnative agricultural pests. A description of them all would fill an entire book. Several prominent and representative examples have been described, however, to provide case studies for subsequent discussions of how government and public–private interventions affect the efficiency of pest prevention and control.

Do Existing Interventions Improve Market Performance?

Government interventions and public–private partnerships fulfill two roles in pest prevention and control. They create incentives for individual producers, consumers, and trade partners to make socially optimal decisions about pest prevention and control. They also help mitigate any remaining gaps between socially vs. privately optimal levels of pest prevention and control after incentive programs are implemented. This section explores how various interventions described above enhance the market performance of pest prevention and control, and agricultural production and marketing in general.

Four criteria are of interest, three of which address market efficiency and another which involves nonmarket outcomes: (1) technical efficiency (maximum output achieved from a given set of inputs); (2) allocative efficiency (inputs allocated to outputs such that a socially optimal bundle of outputs is produced); (3) dynamic efficiency (markets readily adapt to changing conditions); and (4) nonmarket beneficial outcomes (achievement of social goals outside traditional definitions of market efficiency, such as social justice, animal welfare, and human nutrition/health).

Because individual government interventions can affect more than one criterion, this section is organized by interventions. Interventions are grouped together under the same headings used in the previous section: “International Programs”; “Federal Programs”; “Public–Private Partnerships.” Table 12.1 summarizes how interventions address different forms of market failure and affect various performance criteria.

Table 12.1 A synthesis of government and public–private interventions according to the market failures they address (x) and their effects on various performance categories

	Market failures addressed			Performance categories affected			
Intervention	Externalities	Public goods	Imperfect information[a]	Technical efficiency	Allocative efficiency	Dynamic efficiency	Nonmarket outcomes
SPS agreement[b]	x	x	x	+	+	+	+/–
Import inspection and fees	x	x	x	+/–	+	+	n/a
Research and data collection	x	x	x	+	+	+	n/a
Data sharing and research coordination	x	n/a	x	+	+	+	n/a
Certification	x	n/a	n/a	+	+/–	+	+
Compensation and cost-sharing	x	n/a	n/a	n/a	+/–	n/a	n/a
Contingent compensation and pest insurance	x	n/a	n/a	+/–	+	n/a	n/a
Animal disease traceability	x	n/a	x	+/–	+	+	+
Improved screenings and risk assessments	x	n/a	x	+	+	+	n/a

Positive (+), negative (–), ambiguous (+/–), or not applicable (n/a)

[a]Imperfect information is not actually a market failure. Efficient decisions can still be made given imperfect information if market failures such as externalities, public goods, and asymmetric information are absent. Social net benefit arising from efficient decisions is simply lower than it would be if perfect information were available

[b]Sanitary and Phytosanitary Agreement

International Programs

Two interventions at the international scale have sufficiently important effects on US agriculture's market performance to justify further discussion: the World Trade Organization's Sanitary and Phytosanitary Agreement, and a trio of trade-enhancing concepts known as regionalization, compartmentalization, and commodity-based trade.

Sanitary and Phytosanitary Agreement

The World Trade Organization's SPS Agreement improves the *technical* efficiency of US agricultural marketing by indirectly encouraging information exchange and strengthening trade partners' plant and animal health infrastructure. In an unregulated trade environment, we might expect pest-related information and pest prevention and control services to be underprovided because of their public good characteristics. Governments typically address this market failure by providing information and services themselves using taxpayers' dollars or user fees. Some governments are unable or unwilling to do so though, in which case the market failure persists, and both the country and its trade partners suffer. The SPS Agreement provides an impetus for other countries to help trade partners achieve socially optimal levels of pest prevention and control.

Information exchange helps ensure trade partners have the best available scientific information about US agricultural product safety. This alleviates problems arising from imperfect information and reduces the amount of resources (e.g., administrative paperwork, diplomacy, and inspections) needed to gain market access for US products. Strengthening of trade partners' plant and animal health infrastructure, through activities such as scientific exchange, program evaluation, professional trainings, and preparedness exercises, increases their ability to control agricultural pests within their own borders. This reduces the amount of pest prevention necessary at US ports of entry, although much effort is still required, and increases the technical efficiency of the import process.

The SPS Agreement also increases *allocative* efficiency by encouraging trade partners to remove SPS measures that are inconsistent with scientific evidence. This reduces external costs that politically motivated trade barriers might otherwise impose on trade partners and creates opportunities for consumers who place the highest value on agricultural goods to actually obtain them. In general, the SPS Agreement liberalizes international trade, which increases competition in the global market for agricultural products and reduces the ability of individual buyers or sellers to manipulate market prices and quantities.

The SPS Agreement improves some aspects of *nonmarket beneficial outcomes* by creating access to agricultural markets for more countries, which increases wealth and income equality at a larger geographic scale. Similarly, by increasing the number of countries from which a given agricultural good can be purchased, the

SPS Agreement creates more flexibility during times of crop failure or political instability (either domestically or abroad). This enhances *dynamic* efficiency and thereby reduces the impact such events have on a country's economy.

One potential drawback of harmonization, as perceived by some stakeholders involved in actual SPS negotiations, is that once OIE or IPPC has accepted an SPS standard, it is more difficult for a country to impose stricter SPS standards, even when such standards are scientifically justifiable. Although the SPS Agreement's primary benefit is the singling out of unjustifiable SPS standards, some argue it also increases the cost of defending legitimate standards. Presumably though, any decrease in the *technical* efficiency of administering legitimate SPS standards is offset by gains in the *allocative* efficiency of international trade.

The SPS Agreement strives to eliminate the use of politically motivated SPS standards, but it cannot remove politics from the equation entirely. Trade partners may be tempted to engage in strategic behavior, such as "greasing the wheels" for future negotiations by relaxing certain SPS requirements below official standards, or "retaliating" against a trade partner who enforces a scientifically justifiable SPS requirement that exceeds OIE or IPPC's minimum standard (Feinberg and Reynolds 2006). Strategic behavior of trade partners during SPS negotiations, such as "reciprocity" or "tit-for-tat," does not necessarily prevent socially efficient outcomes from being achieved (Norwood and Lusk 2008, p. 284); however, they can sometimes lead to "mutually harmful conflict" (Keohane 1986). Implications of strategic behavior for the technical and allocative efficiency of SPS requirements and international trade are ambiguous because they depend on which strategies trade partners adopt.

Regionalization, Compartmentalization, and Commodity-Based Trade

Three related pest management tools have become increasingly important means for WTO member countries to meet SPS standards: regionalization, compartmentalization, and commodity-based trade. These tools reduce negative externalities that pest-infested agricultural operations impose on pest-free operations by differentiating them. Pest-free operations, as a result, can market their goods internationally despite the presence of pest-infected operations within their home country.

Regionalization draws boundaries around pest-infested regions that are geographically isolated from pest-free regions, and applies trade-restrictions only to them (Livingstone et al. 2006). Recent applications include regionalization for foot-and-mouth disease in South Africa (Bruckner et al. 2002); citrus canker in Argentina (Romano and Thornsbury 2006); highly pathogenic avian influenza outbreaks among domestic poultry in Canada (Loppacher et al. 2008); and bovine tuberculosis, bovine brucellosis, potato cyst nematodes, and others in the United States (Ito and Clever 2010; Livingstone et al. 2006; USDA APHIS 2009b).

For situations in which pest-infested subpopulations cannot be geographically isolated, it might still be possible to reduce their trade impacts on pest-free operations through compartmentalization. Compartmentalization isolates pest-free subpopulations from pest-infested subpopulations through the use of biosecurity measures

(Gemmeke et al. 2008). Livestock operations that use OIE-approved biosecurity measures may apply for permission to participate in international markets. This approach underlies the National Poultry Improvement Program and the pork industry's TCP. It is also used to separate commercial poultry flocks from backyard flocks, the latter of which are more likely to carry avian influenza (Garber et al. 2007). Compartmentalization generally requires monitoring and verification of individual operations, so it is most easily implemented in highly integrated industries.

Commodity-based trade emphasizes the process by which goods are produced, rather than their region of origin, when deciding whether to allow them to be imported. Some animal diseases, for example, spread by fresh meat but not frozen meat, or by bone-in meat but not deboned or cooked meat. These characteristics might therefore be more relevant than the product's country of origin or biosecurity measures in place at the source farm (Thomson et al. 2009). Commodity-based trade allows agricultural products to be imported if they are processed in ways that eliminate risk, regardless of the originating country, region, or farm's pest status (Rich et al. 2009). The United States implements commodity-based trade already, allowing several products from pest-affected countries to be imported if they have been properly treated prior to or upon arrival at ports of entry. APHIS, for example, revised federal regulations in 2009 to allow the importation of cooked pork skins from regions affected with foot-and-mouth disease, swine vesicular disease, African swine fever, or classical swine fever (e.g., Brazil) if they have been cooked using approved methods (USDA APHIS 2009c).

Regionalization, compartmentalization, and commodity-based trade improve the *technical* efficiency of global markets by reducing the cost, in terms of foregone marketing opportunities, of ensuring pest-free imports. They enhance the *allocative* efficiency of global markets by removing barriers to trade for pest-free operations, which allows additional pest-free goods to flow to their highest valued uses and increases competition in global markets. These tools also increase the *dynamic* efficiency of the SPS Agreement by enabling boundaries between pest-free and infected operations to be adjusted more easily in response to changing conditions, as compared to a system that assigns a single pest classification to an entire country. Similarly, compartmentalization increases dynamic efficiency by encouraging biosecurity measures that reduce an operation's vulnerability to future emerging diseases.

All three tools improve certain aspects of *nonmarket beneficial outcomes* (e.g., social justice) by reducing the number of pest-free operations punished for outbreaks on other operations whose management practices are beyond their control. Effects on other aspects of nonmarket beneficial outcomes, such as animal welfare, are more ambiguous. Biosecurity measures associated with compartmentalization, such as indoor confinement of commercial poultry, improve animal welfare by preventing the spread of nonnative diseases via backyard flocks and wild birds. Confinement might also reduce commercial poultry's welfare, however, by preventing benefits from being outdoors (e.g., natural exercise and foraging opportunities), and exacerbating the spread of endemic diseases within the flock. Similarly, game-proof fences in southern Africa that separate foot-and-mouth disease infected areas from uninfected areas improve livestock health in uninfected areas, but also impede wildlife migrations which provide various market and nonmarket goods and services.

Regionalization, compartmentalization, and commodity-based trade are attractive tools for less integrated industries, such as beef, relative to highly vertically and horizontally integrated industries, such as poultry and pork. The inherent diversity of operations in less integrated industries tends to stymie efforts to define and achieve industry-wide pest eradication and management goals. These three tools enable individual pest-free operations in such industries to market their goods internationally regardless of the industry's status as a whole.

Federal Programs

The US government participates in many programs that affect agricultural production and marketing. It has sole responsibility though for inspection of imported goods to prevent nonnative pest incursions. Inspection services mitigate several forms of market failure, and affect every market efficiency category. Because of this broad scope, a thorough discussion follows of inspection services' impacts on market performance, as well as challenges to future efficiency gains.

Inspections at US Borders and Ports of Entry

Inspection of imported goods by US CBP personnel, with assistance from USDA APHIS's SITC unit and other federal, state, and county agencies, increases the *allocative* efficiency of the inspection "market" by mitigating the public goods problem that would otherwise result in private markets under-providing these services. Given the high cost of inspections, and the non-excludability of its benefits, no individual's private benefit is sufficiently high to justify providing these critical services themselves. If the social benefit of inspection outweighs the cost, however, the service should be provided. The federal government fulfills this role by providing inspection services to the public. User fees and fines collected at ports of entry help offset some of the financial burden of providing these services; taxpayer dollars offset the rest. Provision of these services presumably moves us closer to a socially optimal level of inspection and, thereby, increases allocative efficiency.

In the absence of inspection services, foreign goods would be imported to the United States without full consideration of the costs they impose on domestic agricultural producers through nonnative pest incursions. Too many pest-infested foreign goods would be imported in this scenario, relative to a social optimum, and allocative efficiency in the market for imported goods would not be achieved due to negative externalities. The presence of government-sponsored inspection services decreases the number of pest incursions by detecting contaminated shipments and, thereby, increases the allocative efficiency of the imported goods market.

Provision of inspection services may seem costly to the general public, but the economic consequences of allowing devastating nonnative pests, such as foot-and-mouth disease or Mediterranean fruit fly, to freely enter the United States would surely be much higher.

Fees and fines of any reasonable magnitude also have the potential to increase allocative efficiency in the imported goods market by reducing negative externalities imposed by pest-infested imports (Mérel and Carter 2008). USDA APHIS currently charges a user fee to each commercial vessel, aircraft, truck, rail car, and airline passenger entering the country (7 CFR § 354.3). The State of Hawaii charges 50 cents per 1,000 lb of any imported product (State of Hawaii 2008), and California charges $850 for each foreign vessel that enters their ports (State of California 2009). The resulting revenue helps defray the cost of agricultural inspection and quarantine services (USDA APHIS 2009d). Fees also increase the cost of crossing US borders and should therefore reduce the volume of international traffic and associated pest incursions, at least in theory. It is unclear, however, to what extent current fees affect trade volumes, in reality.

Fines for contaminated shipments and other SPS-related transgressions, such as misrepresenting shipment contents, mishandling potentially infected garbage, or tampering with official stamps and seals, are a common tool in the United States (USDA APHIS 2005b, 2012). Contaminated shipments are also regularly treated, rejected (i.e., re-exported), or destroyed at the owners' expense. It is unclear whether the threat of fines, treatment, rejection, or destruction of contaminated or prohibited goods provides sufficient incentive for foreign exporters to invest in pest prevention.

Subversive behavior, such as smuggling of illegal goods or fake certifications, is observed regularly, which suggests that at least some importers believe it is cheaper to ignore SPS standards and break laws, at the risk of being fined, than to comply with them. Perhaps the probability of being caught, or the penalty if caught, or the probability of a penalty being successfully enforced, or all of the above, is too small (Mérel and Carter 2008).

The probability of a penalty being enforced is certainly less than 100%. In 2011, limited resources for investigating violations and collecting fines forced APHIS's Investigative Enforcement Services to select just 600–800 cases to pursue from a backlog of over 2,000 open investigations (Parham 2012). The other 1,200–1,400 cases were dismissed simply due to a lack of resources. In addition to limited investigation and enforcement resources, imperfect information about the probability and cost of pest incursions for various imported goods also makes it difficult to determine the appropriate number and value of fines to impose and enforce.

Returning to inspection services' effects on market efficiency, these services enable consumers to obtain their desired bundle of imported products while imposing fewer nonnative pest incursions on domestic agricultural producers. With fewer nonnative pest incursions, domestic agricultural goods can be produced with less input (e.g., herbicides, pesticides), and marketed more successfully abroad as pest-free, particularly to countries that are also free of the same pest and wish to remain so. Inspection services therefore increase the *technical* efficiency of domestic agricultural production. Inspection services also increase the *dynamic* efficiency of pest control and management by acting as sentinels of future pest incursions. Successful interception of a new nonnative pest at a port of entry, before it has an opportunity to spread, may trigger new research and preparedness planning. Given sufficient advanced warning, researchers and pest managers may be able to devise effective prevention and control strategies before another contaminated shipment causes an incursion.

Although port inspection services increase efficiency in several markets, it is not clear whether they themselves are provided in a *technically* efficient manner. When CBP first took over inspection services in 2003, APHIS raised concerns about the new agency's ability to adequately detect agricultural pests. Additional training and hiring was necessary to achieve historical inspection performance rates. CBP was eventually able to achieve these levels (USDHS CBP 2009), but it is unclear whether CBP consumes more or fewer resources than APHIS did in this same role. Agricultural inspectors are required to report pest-relevant interceptions to the Agricultural Quarantine Activity System (AQAS) for use in the Agricultural Quarantine Inspection Monitoring (AQIM) program (USDA APHIS 2011b); however, it is difficult to extract concrete conclusions about CBP's technical efficiency from this complex dataset.

Suppose, for example, that the number of intercepted agricultural products declined between 2 years. This decline could be due to a variety of factors, such as a reduction in the number agricultural inspectors or the hours they worked; a decrease in inspectors' level of skill or vigilance due to high employee turnover; a reduced volume of goods and people flowing into the United States due to an economic downturn; or an increase in the proportion of cargo or people in compliance with SPS standards due to improved public outreach. It may be difficult to control for these and other effects in the data to determine whether technical efficiency has changed under CBP's leadership. Regardless, we should remain open to the possibility that any decrease in technical efficiency of agricultural inspections that may have occurred could be partially or completely offset by related increases in the technical efficiency of terrorism prevention or enforcement of drug and immigration laws.

Four years after CBP assumed responsibility for agricultural inspections, a review revealed several shortcomings. Many ports of entry, for example, had deficient pest sampling, documentation, and disposal practices (USDHS OIG 2007). Some district field offices and preclearance locations reported lower inspection and interception rates (USGAO 2007). CBP has since taken steps to address these shortcomings, but measures of improvement are not yet readily available. The need might still exist to improve implementation of existing inspection protocols, enhance agricultural inspectors' scientific knowledge, and emphasize the importance of agriculture within CBP's multifaceted mission.

The volume and diversity of goods and people entering the United States through ports and borders have increased tremendously over the last decade. Therefore, the *dynamic* efficiency of inspection services, in addition to their technical efficiency, is of concern. Dynamic efficiency reflects how quickly and effectively inspection services adapt to constantly evolving trade flows and pest threats. Screening technologies and risk assessment procedures must evolve for CBP and APHIS to keep pace with the increasing volume and diversity of international travel and trade. Decision support systems that more quickly and accurately predict the risk of pest incursion associated with individual passengers and cargo are also needed.

Scientists with APHIS PPQ are currently developing such tools, including a model that assigns risk ratings to individual countries' cargo and airline passengers based on recent outbreaks in the country of origin, past SPS violations, and flight information (USDA APHIS 2010b). These tools will increase APHIS's responsiveness to changing trade patterns and emerging pest threats and, therefore, increase the dynamic efficiency of pest prevention. Technologies that increase the proportion of passengers and cargo CBP and APHIS SITC personnel can screen are also needed. The incredible volume and diversity of plant species and plant-derived products imported to the United States make plant pest prevention an increasingly daunting task. The small number of agriculture specialists stationed at US ports of entry (roughly 2,000) simply cannot inspect a sufficiently large proportion of cargo, passengers, and mail to detect all potential invaders or even the highest priority invaders.

Within the relatively small proportion of shipments agriculture specialists are able to inspect, pests may be overlooked because it is infeasible to examine every square inch of a shipment. It is too time-consuming to off-load its entire contents, and materials at the center of a chosen pallet are difficult to access. Furthermore, pests can hide in packaging materials that are not properly treated with heat or methyl bromide. International standards exist for treating wood packaging materials (USDA APHIS 2004), but materials are sometimes improperly stored in pest-infected locations and reused without being retreated. Additionally, some importers falsify documents to avoid packaging material treatment costs. Subversive behaviors such as this make agriculture specialists' jobs even more complicated and daunting.

Continued improvement of high-throughput screening, advanced detection technologies, and more fraud-proof documentation may help overcome some of these inspection challenges. Such improvements might increase technical efficiency, assuming they enable inspectors to detect more pests using fewer resources. Alternatively, some inspection challenges could potentially be addressed by hiring more inspectors, SITC officers, and canine teams. By placing more boots on the ground, CBP and APHIS might be able to achieve higher rates of inspection and detection without making large upfront investments in expensive new technologies.

Technical efficiency of international trade might also be improved in more subtle ways, such as the development of affordable substitutes for wood packaging materials (e.g., rubber or plastic pallets). Environmental benefits and costs of alternative materials would need to be weighed carefully though. Rubber or plastic packaging materials might slow the spread of nonnative wood-boring insects, but have a bigger environmental footprint than wood packaging materials (e.g., carbon emissions). Research and development costs would also need to be considered carefully. If the economic value of resources used to develop a new technology exceeds the value of resources conserved by that technology, then that technology might actually decrease technical efficiency rather than improve it.

Animal pests present some unique challenges for agriculture specialists, as compared to plant pests. A smaller volume and diversity of animal species, products, by-products, and pests move through international trade relative to plants, so animal-pest incursions are likely to occur less frequently. One potential downside of this otherwise positive characteristic is that agency personnel might encounter fewer animal pests during their careers than plant pests and, therefore, have less experience detecting them. Experiments by Wolfe et al. (2005) show that if human subjects do not find what they are looking for relatively frequently, they often fail to notice it when it does appear. This suggests that if animal pests are encountered less frequently than plant pests, inspectors may have a higher chance of failing to detect animal pests when they are actually present (Wolfe et al. 2005).

The potential for detection errors is mitigated to a large extent by import rules that are based on regions-of-origin and product characteristics rather than actual pest detection (USDA APHIS 2011c). Veterinarians are also available at most ports of entry to assist CBP inspectors whenever questions arise. The ability of inspectors to identify and detect animal pests is still important, however, because animal products may be intentionally mislabeled to conceal their true region-of-origin. On paper, a product may appear to be from a pest-free region, but it may have been smuggled from a pest-infected region into a pest-free region (for example, across a regionalization boundary) before being transported to the United States (Loppacher et al. 2008). Similarly, animal products from pest-free regions could become contaminated during transit if ticks move from one cargo container to another (USDA APHIS 2011c). If an inspector rarely sees ticks during their typical work day, research suggests they might fail to notice ticks when they are indeed present (Wolfe et al. 2005).

Another potential downside of relatively infrequent nonnative animal pest outbreaks in the United States is that animal health officials depend heavily on lessons learned from hypothetical outbreak exercises, outbreaks in other countries, or indigenous pest outbreaks (e.g., bovine tuberculosis and low pathogenic avian influenza). Although more effective screening and risk assessment tools would enhance animal pest prevention, more frequent and effective training of animal health experts in pest recognition and outbreak preparedness might also be beneficial.

In the future, dynamic efficiency will be critical to the success of CBP and APHIS's pest prevention and detection efforts, not only because of increasing volumes of international trade but also because of global climate change, which may change the distribution of international trade and nonnative pests. Changes in temperature and precipitation will likely affect the distribution and frequency of pest outbreaks, especially those associated with insects and migratory animals. The potato psyllid from Mexico, for example, is now capable of overwintering in California and hence inflicting more damage on the potato, tomato, and pepper industries (Trumble and Butler 2009). The geographic range of arthropod-borne diseases, such as Rift Valley fever, is also closely tied to climatic conditions and therefore expected to shift or expand in the future (Gould and Higgs 2009). The spatial distribution of migratory animals and diseases they carry (e.g., migratory waterfowl with avian influenza, or whitetail deer with tick-borne diseases) will likely also change (Gilbert et al. 2008; Hoberg et al. 2008).

Prediction of future geographic distributions of nonnative pests is matched in difficulty by the prediction of climate change's possible impacts on supply and demand of agricultural goods, and subsequent patterns of international trade. APHIS is collaborating with scientists at partner institutions to develop forecasting systems that allow them to incorporate climate change scenarios into pest risk models (USDA APHIS 2010b). Socioeconomic impacts of climate change must be considered simultaneously, however, with physical and biological impacts to accurately forecast future pest risks and identify efficient adaptations of inspection services.

Some possible socioeconomic impacts of climate change, such as political instability, may have indirect but important implications for nonnative pest risks. For example, escalation of violent crimes in northern Mexico caused APHIS to close three agricultural inspection stations just south of the US-Mexico border to protect employees' safety. These closures changed the location and volume of cattle entering the United States from Mexico; hampered efforts to inspect cattle for fever ticks; and prevented monitoring and fumigation of Mexican fruit flies (Smith-Anderson 2010). More broadly, these events interfered with long-term efforts to maintain a buffer zone at the US-Mexico border between uninfected and infected regions. This unfortunate situation demonstrates the potential for socio-political instability in other countries, whether driven by climate change or other factors, to reduce APHIS's ability to protect US agriculture from nonnative pests. Given the complexity, interdependence, and uncertainty of international trade patterns and associated pest risks, including those possible under climate change, dynamic efficiency will be critical to APHIS's ability to protect US agriculture from nonnative pests in the future.

Public–Private Partnerships

Prevention and control of nonnative agricultural pests is a monumental task, one that the US government cannot undertake alone. Partnerships with non-governmental organizations, such as producer associations and university researchers, provide a critical means to improve the market performance of pest prevention and control efforts. Four types of public–private partnerships, and their associated impacts on market efficiency and nonmarket beneficial outcomes, are discussed in this section: research and data collection; data sharing and research coordination; certification; and compensation and cost-sharing.

Research and Data Collection

Applied research and data collection efforts through the USDA's AQIM program, NAHMS, Agricultural Research Service (ARS), CAPS, and soybean rust monitoring program, potentially increase the *technical*, *allocative*, and *dynamic* efficiency of pest monitoring and control and, hence, the efficiency of US agricultural production and marketing. ARS's applied research improves our understanding of pest biology and the effectiveness of alternative management practices. It also leads to innovations that achieve the same pest control outcomes with fewer resources, or better outcomes with the same resources. In doing so, it increases the technical efficiency of pest control.

Research often exhibits public goods characteristics because the knowledge it produces is non-rival and non-excludable. Private investment in research therefore suffers from free-riding, which results in less research being conducted than is optimal for society. Public investment in research is needed to fill this investment gap, but it is difficult to determine exactly how much research is needed. Such investment improves the allocative efficiency of the market for research on pest prevention, detection, and control. Publically funded research also enhances dynamic efficiency by generating knowledge and technology that raises awareness of emerging pest issues and enables stakeholders to respond and adapt more quickly and effectively.

Allocative efficiency is improved because publicly funded research results are typically available to all producers, both nationally and abroad. Private research by large agribusiness firms, in contrast, is rarely made available to all producers. This places large firms, who can afford to invest in private research, at an advantage over smaller, less wealthy firms. Publicly funded research reduces the knowledge and technology gap between large and small firms, and therefore mitigates circumstances that would otherwise exacerbate market power.

Publicly funded research is vulnerable, however, to macroeconomic forces; when economic growth slows, research funds dwindle. If funds for pest-related research diminish for too long, the risk increases of falling too far behind rapidly evolving patterns of pest distribution, international trade, and agricultural producers' needs. Cold treatments and methyl bromide fumigation methods, for example, were developed many decades ago. Since then, packaging techniques have evolved towards tightly packed pallets and cargo containers, which impede the ability of cold treatments and methyl bromide fumigation to reach materials located in the center. New treatment methods are needed to help maintain technical efficiency in pest prevention and control, but funds for research are becoming increasingly difficult to secure.

Pest surveillance and reporting generally suffer from public good characteristics and positive externalities, which reduce the allocative efficiency of markets that provide these services. Government-funded programs and public–private partnerships that collect data on pest abundance and distribution (e.g., NAHMS, CAPS, soybean rust monitoring network) mitigate these market failures. They also move society towards more complete information. Imperfect information often results in too few or too many inputs being allocated to pest prevention and control relative to the quantity allocated if perfect information were available. By improving the availability of information, data collection increases the magnitude of potential benefits from pest prevention and control.

Data Sharing and Research Coordination

Although data collection increases allocative efficiency, government agencies must either find more technically efficient ways to collect data or find ways to extract more benefit from existing data. Public–private partnerships and the services they provide, such as the NISC and its ISIN, provide low-cost ways for disparate agencies, programs, researchers, and citizens to share and access data. Online information databases, such as ISIN, increase awareness among researchers of data already collected or currently being collected, which reduces redundancy in data collection efforts, thus, increasing *technical* efficiency.

By improving the technical efficiency of data collection, ISIN also increases the technical efficiency of pest detection and control and, hence, the technical efficiency of US agricultural production and marketing. The same is true for NISC's effort to coordinate research projects and priorities across agencies. Coordination increases the net benefit gained from limited research dollars by reducing redundancies and by identifying projects with the greatest expected net return. Research dollars conserved can then be redirected to support additional projects. This process increases the *technical* and *allocative* efficiency of pest-related research.

Data sharing and research coordination also enable scientists to compare and combine datasets and ideas in new ways, which generates new insights about pest prevention and control and fosters development of new technologies and management strategies. Free markets cannot achieve the socially optimal level of data sharing and research coordination because private vs. social benefits and costs of these activities are not equal. It can be difficult, for example, to enforce intellectual property rights to information or research ideas once you have shared them with others. This is especially true when information or ideas are shared online, where they quickly become non-excludable goods. A lack of enforceable property rights creates a disincentive for individuals to share information and ideas, even if the resulting insights and breakthroughs would benefit society as a whole. NISC and ISIN help mitigate this public goods problem by establishing ground rules that protect intellectual property rights and by lowering the private cost of data sharing. Ultimately, more open sharing of data and ideas increases both the *technical* efficiency of data collection and the *allocative* efficiency of pest research.

Data sharing and research coordination also increases the *dynamic* efficiency of pest prevention and control by providing quicker access to additional and more diverse information. This enables agencies to respond more quickly and effectively to new pest threats and outbreaks. One of the biggest challenges in pest prevention and control is anticipating new threats. Access to a global database of pests and pest experts, through online resources such as ISIN, will increase APHIS's awareness of emerging pests and enable them to connect more quickly with relevant experts. By learning from other countries' experiences and experts, the United States will be better able to anticipate, prevent, and control emerging pests.

Certification

Individual producers' pest management decisions often impose benefits and costs on others. Such externalities prevent the free market from achieving socially optimal pest prevention and control levels, and decrease its allocative efficiency. A variety of tools can be used to equilibrate private and social benefits and costs. The National Poultry Improvement Program (NPIP) and TCP represent novel ways of rewarding poultry and pork producers who implement best management practices for specific animal diseases.

Producers who meet the NPIP or TCP's management and monitoring criteria are allowed to place a label on their product certifying it as disease-free. Certification makes it easier to market their product to consumers, particularly those in international markets. Access to additional consumers implies higher demand for the product and, potentially, a higher price received or larger quantity sold. The opportunity for higher profit through certification increases producers' incentives to invest in pest prevention and control. This partially mitigates externalities in the market for pest prevention and control and thereby increases *allocative* efficiency.

Voluntary certification programs affect other types of efficiency as well. By raising producer awareness of best management practices in pest management and control, certification increases the *technical* efficiency of agricultural production. Producers with better training and more information should be able to achieve greater pest prevention and control from a given set of resources. Improved pest prevention and control can also enhance *nonmarket beneficial outcomes* by reducing disease incidence among animals (perhaps humans as well) and subsequently improving animal and human welfare.

The public–private framework in which NPIP and TCP operate might also enhance the *dynamic* efficiency of pest prevention and control. The NPIP was originally created to address pullorum disease in poultry. After producers reduced the disease's prevalence to satisfactory levels, NPIP shifted emphasis to other diseases of concern, most recently low pathogenic avian influenza and *S. enteritidis*. The NPIP's partnership between producers, their national association, and government agencies provides an effective communication channel through which producers and researchers can inform each other about emerging pests, and collaboratively identify and implement effective responses. Ideally, the TCP will evolve, as the NPIP has, to address emerging pest issues in the pork industry long after trichinosis is defeated.

Certification's effect on market power and hence *allocative* efficiency is less clear. Large producers might be more interested in gaining access to international markets than small producers and, therefore, be more likely to participate in certification programs. As large companies export more of the product abroad due to certification, small producers in the exporting country might benefit from decreased supplies and higher output prices in the domestic market. Producers in importing countries, in contrast, might be harmed by certification in the United States as supplies in their domestic market increase and output prices decline. Falling prices in the importing country's domestic market could potentially affect small operations more severely than large, in which case certification might cause consolidation in the importing country's agricultural industry.

Overall, certification increases global competition and therefore increases allocative efficiency on a global scale. Its net effect on social welfare and income distribution at smaller geographic scales, however, is more ambiguous. Subversive behavior, such as falsification of labels, negatively affects certification programs' technical efficiency and ability to improve the allocative efficiency of international trade. Technical efficiency is reduced because valuable resources are used not only to undermine the certification system, but then to control pest outbreaks caused by falsely certified products and develop fraud-proof labels. Falsification of certification labels reduces certification's ability to improve the allocative efficiency of international trade by undermining a program's reputation among trade partners. If trade partners do not trust certification labels, they may revert back to individual animal testing requirements, which would push producers out of the market who have already invested in best pest-management practices. This would reduce the allocative efficiency of international trade in certain agricultural products.

Looking towards the future for certification programs, one hopes the poultry and pork industries' successes with a "partnership approach to pest management" will not be thwarted by subversive behavior and will eventually inspire the beef industry to adopt a similar framework. Some adaptations may be necessary to accommodate the beef industry's more heterogeneous and disparate structure. One significant barrier to adoption is that certification would require an animal disease traceability system capable of clearly and easily tracing beef products back to the packing plants, feedlots, and cow-calf operations from which they originated, along with the pest management practices in place there. Unified support for a mandatory national animal identification system (NAIS) does not currently exist in the beef industry, but support is relatively strong for development of a national policy that enhances animal disease traceability. This topic is discussed in more detail towards the end of the chapter.

Compensation and Cost-Sharing

Compensation for crops or livestock destroyed during control or eradication campaigns, and cost-sharing for the adoption of best management pest prevention and control practices increase the *allocative* efficiency of pest control by mitigating market failures that arise from negative externalities. When deciding whether to report a pest outbreak or adopt best management practices, a producer might consider only the private benefits and costs of doing so, and fail to consider benefits and costs to the industry as a whole. In the case of reporting or adopting, a producer underestimates the social benefits of their actions and, therefore, chooses to undertake these activities too infrequently.

The tendency to underreport pest outbreaks is exacerbated if government agencies respond to outbreaks by destroying entire fields or herds without compensating the owner. This increases the private cost of reporting, and reduces the likelihood a producer will choose to report. Compensation for destroyed crops and livestock, in contrast, reduces the private cost of reporting, increases the likelihood a producer will report and, therefore, improves the government's chance of successfully controlling the pest. The same is true for cost-sharing to encourage adoption of best management practices.

Compensation for destroyed crops and livestock has some negative consequences though. It reduces an affected producer's private cost of pest incursion, and thus provides a disincentive for them to invest in prevention. This unintended consequence has the potential to decrease the allocative efficiency of pest prevention and control. Government agencies have historically accepted this trade-off between increased reporting and decreased prevention. As budgets tighten during times of economic recession though, agencies increasingly look for compensation mechanisms that not only increase reporting but also increase prevention. Compensation mechanisms that generate their own source of funding, such as user fees at ports of entry that help fund agricultural inspections, are also needed so agencies can guarantee compensation regardless of the size of the government's general fund.

Compensation raises questions about nonmarket issues, such as equity, social justice, and animal welfare. Taxpayer dollars are often used to compensate agricultural producers for pest-related losses and pest eradication efforts. These activities increase the allocative efficiency of pest control, primarily to the benefit of the agriculture industry, but are costly and sometimes detrimental to other members of society. Some people may view this wealth transfer as inequitable and hence detrimental to nonmarket beneficial outcomes.

Residents of California, for example, expressed concerns about the potential health and environmental effects of USDA's plan to spray an unregistered pesticide over residential areas to control the light brown apple moth (a nonnative pest of trees and agricultural crops). Public outcry resulted in a delay of the light brown apple moth eradication program until the pesticide's ingredients and potential health effects were made public (Kay 2008; Van Rein 2007). In a different case, homeowners whose backyard citrus trees were destroyed to protect Florida's commercial citrus industry sued the federal government over inadequate compensation (Kamprath 2005). Similarly, California residents affected by the culling of exotic pet birds and backyard poultry during an outbreak of exotic Newcastle disease protested emergency response actions they perceived as inhumane and unconstitutional (Daley 2003). These examples underscore the relevance of equity, social justice, and animal welfare issues to pest control efforts and compensation. They also highlight the potential for trade-offs between market efficiency and nonmarket beneficial outcomes, which should be considered in the design of pest control plans.

Emerging Tools

New incentive-based approaches for reducing market failures are constantly being developed and refined. Economists and policymakers have been working for some time to design and deploy two particular sets of tools that may improve the market performance of pest prevention and control: (1) contingent compensation and pest insurance and (2) a NAIS. Neither set has been implemented successfully in the United States yet, beyond a pilot or voluntary scale. This may be due, in part, to the complex and somewhat ambiguous impacts they are anticipated to have on various categories of market efficiency and nonmarket beneficial outcomes.

Contingent Compensation and Pest Insurance

Efforts are underway to improve the allocative efficiency of existing government compensation programs for crops and livestock destroyed during control and eradication campaigns by making them contingent on a farm's biosecurity and pest control practices, or how quickly the operator reports an outbreak (Horst et al. 1999). Contingent compensation would encourage producers to invest more in pest prevention even in the presence of government safety-nets, and report potential outbreaks as soon as symptoms are detected. The financial sustainability of contingent compensation could be enhanced by requiring producers to contribute a fixed dollar amount per operation or per unit of product sold, similar to an existing beef check-off program (Horst et al. 1999).

Pest insurance has been proposed as another means to achieve a self-sustaining compensation program (Grannis et al. 2004; Gramig et al. 2009). Compensation in this case would be contingent on enrollment in a pest insurance program, rather than adoption of biosecurity or pest control activities. This might reduce verification costs associated with compensation, but pest insurance would likely suffer its own suite of market failures, such as adverse selection, moral hazard, and asymmetric information (Gramig et al. 2009).

Adverse selection occurs when individuals who face high levels of risk purchase insurance to a greater extent than low-risk individuals. This imbalance in the insurance pool increases the probability insurance companies will have to pay claims, which drives up the price they charge and causes even fewer low-risk individuals to purchase coverage. Adverse selection makes it difficult for insurance companies to enroll a sufficiently diverse and abundant pool of customers to be profitable. If adverse selection is sufficiently severe, or if pest outbreaks are sufficiently widespread, pest insurance might not be financially self-sustainable. It might instead suffer the same fate as the federal crop insurance program, which relies on highly subsidized premiums to achieve the government's desired level of producer participation (Glauber 2004).

Moral hazard occurs when people take greater risks because they have insurance coverage and believe it reduces the financial consequence of their risky behavior. A crop producer with pest insurance, for example, might spend less time scouting fields for weeds, insects, and diseases. A livestock producer with pest insurance might undertake fewer biosecurity measures when introducing new animals into the herd. Moral hazard can be reduced by imposing a deductible, or making coverage contingent on adoption of best management practices. The latter might require verification of practices before claims are paid though, which would increase the program's administrative costs.

Asymmetric information occurs when insurance customers know more about their risk-taking or risk-reducing behaviors than do insurance companies. This makes it difficult for insurance companies to distinguish between high and low-risk customers; detect moral hazard; determine the appropriate price to charge individual customers for coverage; and identify fraudulent claims. Asymmetric information exacerbates the effects of adverse selection and moral hazard, making it even more difficult to design effective pest insurance products (Gramig et al. 2009).

If an effective insurance product could be designed, it would increase the *allocative* efficiency of pest prevention and control by allowing producers who are less willing to incur the financial consequences of pest outbreaks to transfer that risk to insurance companies who are better able to manage it. An effective insurance product would also provide a self-sustainable means of encouraging more pest prevention and reporting compared to levels achieved under existing unconditional compensation programs. Inefficiencies would still exist, however, because the decision to purchase insurance would itself suffer from externalities. Producers would make their pest insurance decision without consideration for the benefits and costs it imposes on other people; therefore, the socially optimal level of pest insurance coverage would not be achieved.

Pest insurance might not increase the *technical* efficiency of pest prevention and control either. Agricultural insurance programs often incur large administrative costs and taxpayer-funded subsidies. Any efficiency gains that pest insurance could generate might be achieved more cheaply through other interventions discussed in this chapter.

Animal Disease Traceability

In the wake of a foot-and-mouth disease outbreak in the United Kingdom, and terrorist attacks on the United States in 2001, USDA APHIS began collaborating with animal health experts and livestock industry representatives to design a mandatory NAIS (Anderson 2010). Mandatory NAIS would enable officials to quickly trace an individual animal that tests positive for a disease or other agent of concern to the farm of origin, and identify all contact herds. Complete traceback within a 48-hour period would empower officials to act more quickly and effectively during an animal health emergency (Murphy et al. 2008). This would reduce the extent to which foreign animal diseases spread before quarantines can be put in place. It would reassure domestic and international consumers that US livestock products are traceable and therefore relatively safe, and encourage international trade partners to keep borders open during an outbreak (Murphy et al. 2008).

The US Animal Identification Plan, first released in 2003, proposed to assign a unique identification number to each livestock operation, sale barn, and packing plant; permanently affix a unique identification number to each individual animal or group of animals; and create an animal tracking database to which relevant livestock movements would be reported (Murphy et al. 2008). The proposal triggered significant opposition, especially from the cattle industry (Anderson 2010; Knutson 2010), due to concerns about the government's ability to protect the confidentiality of farm-level data; the cost to individual producers of purchasing the required technology and reporting livestock movements; and the lack of, or unequal distribution of, benefits to individual producers (Anderson 2010).

USDA APHIS eventually abandoned the idea of a mandatory system. A voluntary program existed for a brief period, but only 40% of the 1.4 million premises in the United States with livestock chose to register (USDA APHIS 2010e). Much higher levels of enrollment would have been necessary to realize the full benefits of traceability. Low enrollment in this voluntary program was not unexpected. A producer's private benefit from registering is less than society's benefit (i.e., enrollment generates positive externalities); therefore, we would expect fewer producers to enroll in a voluntary system than society would like (Knutson 2010). Premiums for livestock from registered farms, or price penalties for livestock from unregistered farms, would have been necessary to increase enrollment to socially optimal levels (Anderson 2010; Schulz and Tonsor 2010).

Given the unpopularity of premise registration, USDA APHIS revised the emphasis of their proposed program to focus on animal disease traceability, particularly for interstate livestock movements. A draft rule put forward in 2011 would improve traceability by establishing minimum national official identification and documentation requirements for livestock moving interstate (USDA APHIS 2011d). Its first requirement is that animals moved interstate would have to be officially identified. Some species would have a unique identification number, while others would be identified as a group or flock. Several identification methods and devices would be acceptable, and states could agree to approaches not included on the national list. This would accommodate states that already have an animal identification system in place (e.g., registered brands and official brand inspectors). For states without established systems, a national minimum standard would provide guidance on acceptable forms of animal identification and encourage harmonization of requirements.

A second requirement of the draft minimum standard is that livestock being moved across state borders would have to be accompanied by an interstate certificate of veterinary inspection (USDA APHIS 2011d). The certificate would contain information about the animals' origin and destination. It might also contain individual animals' official identification numbers, particularly in the case of breeding, rodeo, and recreational livestock, which are relatively long-lived and might have greater potential to spread disease (as compared to steers and spayed heifers being shipped to feedlots or abattoirs, for example).

Animal identification and documentation, in general, generate more benefit for society as a whole than for individual livestock producers (i.e., they generate positive externalities). Therefore, in the absence of regulations or incentives, too few producers will undertake them and the *allocative* efficiency of animal disease traceability will be reduced. A national minimum standard for animal identification and documentation would enhance allocative efficiency by requiring producers who move animals across state borders to participate in these activities. This is assuming the cost of program administration does not exceed the expected benefits (see USDA APHIS 2011d for estimated costs of the proposed rule).

The proposed animal traceability rule's primary benefit would be the reduction of economic losses during future livestock disease outbreaks. Quicker traceback capabilities would reduce uncertainty about infected animals' herd of origin, and herds they may have contacted. This would enable emergency responders to quarantine or cull fewer herds, which would improve animal welfare and, hence, *nonmarket beneficial outcomes*. Similarly, the ability of animal health officials to respond more quickly and effectively to emerging diseases would improve the *dynamic* efficiency of US agricultural production and marketing.

The *technical* and *allocative* efficiency of animal disease response and control, however, would not necessarily improve. Recall that imperfect information is not a market failure. Animal health officials' decisions might already be efficient given the limited information available to them. Nonetheless, the magnitude of losses during animal health emergencies would decrease, and if these cost savings exceed the cost of implementing the rule, society's well-being would increase (i.e., the size of the economic pie would grow). One final note about the proposed national minimum standard is that it offers individual states tremendous flexibility when choosing their preferred animal identification methods and devices. This would afford each state the opportunity to identify *technically* efficient solutions for their unique circumstances and needs, although it would not guarantee such an outcome.

What Have Interventions Achieved Overall?

Externalities and public goods reduce the ability of free markets to achieve socially optimal levels of nonnative agricultural pest prevention and control. These market failures hamper the technical, allocative, and dynamic market efficiency of US agricultural production and marketing, and may also impact nonmarket beneficial outcomes. Imperfect information reduces the economic benefits possible from limited resources available for pest prevention and control. A variety of government interventions attempt to correct or mitigate market failures and imperfect information. Table 12.1 summarizes the types of market failures each intervention addresses, and how each intervention affects various market efficiency and nonmarket beneficial outcome criteria.

Nearly every intervention explored in this chapter attempts to fix or mitigate externalities. Externalities are abundant in pest prevention and control due to pests' ability to spread from one agricultural operation to another and because individual producers' activities affect the overall pattern of pest occurrence. Without the many interventions that target externalities, the allocative efficiency of US agriculture would decline.

Although public goods and imperfect information are less ubiquitous than externalities, they create equally difficult challenges for efficient pest prevention and control. Fewer interventions exist to address these challenges because their underlying causes are harder to address than those underlying externalities. Interventions that address public goods and imperfect information (e.g., the SPS Agreement, import inspection, and research and data collection) consist primarily of government provision of goods and information that free markets are unwilling to supply. Provision of public goods and information at a socially optimal level increases the allocative efficiency of pest prevention and control. It also increases the technical, allocative, and dynamic market efficiency (and, in some cases, nonmarket beneficial outcomes) of US agricultural production and marketing. In summary, the few interventions available to address public goods and imperfect information problems are sufficiently effective that no obvious policy gaps remain.

Based on the right half of Table 12.1, existing interventions seem to target technical, allocative, and dynamic efficiency more commonly than nonmarket beneficial outcomes. The lack of emphasis on nonmarket beneficial outcomes should be scrutinized more carefully to determine if policy gaps truly exist. One should not immediately conclude that more should be done to enhance nonmarket beneficial outcomes. It could be that few interventions have been developed to address the lack of nonmarket beneficial outcomes because little evidence exists of a need to increase them. Additional investigation could be undertaken to identify specific cases and causes of underprovision of nonmarket beneficial outcomes in pest prevention and control. A more plausible explanation for the lack of interventions that affect nonmarket beneficial outcomes is simply a lack of awareness. Even economists, whose discipline specializes in identifying socially optimal outcomes, lack technical training in concepts outside the traditional realm of technical and allocative efficiency. A synthesis of this book's individual chapters may help substantiate or refute this hypothesis.

An alternative and perhaps most-plausible explanation could be that potential net gains from improving nonmarket beneficial outcomes have historically been small relative to those from addressing market inefficiencies. Economic theory suggests that limited resources for improving social net benefit from pest prevention and control should be allocated to the market or nonmarket performance criteria in which they would generate the biggest benefit per dollar invested. Many existing pest prevention and control interventions were developed at a time when nonmarket beneficial outcomes were viewed as less important, relative to market efficiency challenges, to justify investment. Now that many technical and allocative efficiency challenges have been addressed, nonmarket beneficial outcomes might finally have the largest payoff per dollar invested. For example, given the small amount of resources invested thus far in animal welfare, relative to the amount invested in import inspections, the next dollar invested in animal welfare (to enhance nonmarket beneficial outcomes) might generate more benefit than another dollar invested in inspections (to enhance allocative efficiency).

Efforts to allocate scarce resources amongst the various market efficiency categories and nonmarket beneficial outcomes, based on their relative payoff, are complicated though by interdependencies. Some interventions improve one category at the expense of others. Compartmentalization of the poultry industry, for example, increases allocative efficiency, by reducing externalities between backyard and commercial flocks, but potentially reduces nonmarket beneficial outcomes by confining birds to indoor facilities that potentially reduce animal welfare. Similarly, animal disease traceability may increase dynamic efficiency, by enhancing preparedness for disease outbreaks, but potentially decreases allocative efficiency by imposing disproportionate costs on small operators and thereby enhancing large operators' market power. Such trade-offs should be considered carefully before resources are allocated to new interventions, or reallocated amongst existing interventions. An intervention that decreases technical, allocative, or dynamic efficiency is not necessarily bad, as long as it generates sufficiently valuable increases in nonmarket beneficial outcomes. Conversely, an intervention that increases non-market beneficial outcomes is not necessarily good if it generates sufficiently large reductions in technical, allocative, or dynamic market efficiency.

A final observation from Table 12.1 is that some interventions generate broader and less ambiguous impacts than others. The purpose and impact of the SPS Agreement, for example, are easier to classify than those for pest insurance. The purpose and impact of research and data collection are easier to classify than those for animal identification. Interventions with narrower and more ambiguous impacts are not necessarily inferior. It is more difficult, however, to determine whether their net impacts are positive. It is also easier to lose sight of the original motivation for an intervention, and invest resources in ways that do not serve the original purpose. Greater scrutiny of interventions, including open discussions of their purposes and capabilities, is needed to determine whether they actually enhance the social net benefit arising from pest prevention and control.

Policymakers can critique a proposed intervention's ability to enhance market performance by seeking answers to the following questions: (1) Is this intervention actually needed; what market failure would it address? (2) Would this intervention generate more benefits than costs? (3) Would investment in some other pest-related intervention generate greater net benefit than the proposed intervention? (4) Would investment in some other aspect of agricultural production and marketing, unrelated to pests, generate greater net benefit than the proposed pest intervention? (5) How would the intervention affect not just technical, allocative, and dynamic market efficiency, but nonmarket beneficial outcomes as well?

Question (1) reminds us that in the absence of market failures, free markets are capable of achieving efficient outcomes on their own; therefore, an intervention should not be imposed without justification. Questions (2) through (4) help assess an intervention's allocative efficiency, a goal that economists continue to focus on, and perhaps for good reasons. Question (5) reminds us, lastly, that technical, allocative, and dynamic market efficiency as well as nonmarket beneficial outcomes are all important goals, but that trade-offs between them could exist and should be weighed carefully.

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