# Food Safety, the Environment, and Trade

**David Zilberman, Gal Hochman, and Steven E. Sexton***

Department of Agricultural and Resource Economics
University of California at Berkeley
zilber@are.berkeley.edu

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* Prepared for the World Bank's Conference on the Political Economy of Distortions to Agricultural Incentives, Washington DC, 23-24 May 2008. While I was writing this paper, two giants of the agricultural economics profession, Bruce Gardner and Ed Schuh, passed away. I am grieved by their loss. They were gentlemen, scholars, and mentors to us all. They made important contributions to the subject matter of this article, as well.

# Food Safety, the Environment, and Trade

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As globalization continues apace and demand for trade liberalization remains strong among developed and developing countries, growing concern about environmental amenities, food safety, and human health has given rise to policy that can significantly curtail international trade. By exposing countries to foreign pests and disease, trade has undoubtedly imposed considerable damage on food systems and ecosystems. In some cases, however, regulation intended to protect a nation’s food supply, and environmental and human health serves to protect domestic producers at the expense of free trade. Paradoxically, as the food supply has grown safer and environmental protection stronger, the level of acceptable risk to human and environmental health has grown smaller, particularly in developed countries. This has yielded demand for ever-more stringent regulation. As the Doha Round of trade talks continues, environmental and resource issues present a challenge to the World Trade Organization (WTO), which must determine mechanisms to address environment and food contamination while precluding the use of environmental and health policy as trade barriers. It is important for the international community to recognize the interdependence of trade and resource policy and to agree to a framework that measures risk as accurately as possible and weighs it against the benefits of trade. In such a framework, the best available science must be accepted as a foundation for policy rather than demagoguery and a precautionary approach. Economics offers such a framework.

In this paper, we discuss the ways in which national governments, firms, and individuals respond to policy related to food safety, environmental protection, and trade. These responses must be considered in the development of policy to ensure the best possible outcomes. We develop a model of risk analysis that relies on interdisciplinary knowledge and the best available science. It accounts for uncertainty about policy impacts and scientific knowledge and incorporates stochastic environmental factors. We argue that use of such a model in the development of health and environmental policy can overcome capture by domestic forces opposed to trade liberalization. The effectiveness of policy, of course, is dependent upon firm and consumer response to policy. We consider the optimization of exporting firms amid a framework of import inspection and find that increased inspection may not reduce risk to food safety or the environment. Section 1 describes the impacts of international transfer of species and genetic material, paying particular attention to the introduction of alien invasive species. Section 2 discusses issues surrounding trade in environmental amenities. Food safety and environmental regulations are reviewed in Section 3, along with mechanisms by which such policy can serve as a proxy for protectionists. Section 4 develops a risk assessment model that can be used in policy design. Section 5 considers the role of institutional, firm and individual behavior in the development and effectiveness of policy. Section 6 summarizes our analysis in offering an agenda for trade talks.

## Section 1: Gene and Species Transfer

The transfer of genetic material and species among nations is central to the protection of natural resources and human health. Though these transfers receive less attention in public debates than commodities trade and financial transfers, they are of paramount importance in a world of heightened interest in environmental and human health. Such transfers can be intentional or accidental and can be responsible for significant environmental and health benefits or costly damage. For instance, in many parts of the world, nutritional needs are primarily met by the cultivation of crops intentionally introduced from other regions (Hoyt 1992). The United States is the leading producer of corn and soybean, crops with origins in Mexico and China, respectively. On the other hand, 80 percent of endangered species worldwide are threatened by invasive alien species, which are responsible for nearly half of all invertebrate extinctions with known causes (Stein and Flack 1996; Wilcove et al. 1998).

The two most significant benefits of international gene and species transfer are their contributions to food provision and chemical pest control reduction. As already mentioned, much of the world’s food is produced by crops that humans introduced from foreign lands. None of the staple crops in North America are indigenous. The grasses that occupy U.S. pastureland were intentionally introduced to provide better livestock grazing. Many of the fruits consumed today are the product of plant breeding with genes from different regions. Genes from Andean corn, carefully bred in Mexico City, ended a century-long effort to improve the nutritional content of corn and yielded modern corn. The assault of the rusts on cereal crops has led to famine over the course of human history. An intense international effort to develop rust resistance in wheat has yielded a partial solution and perhaps averted untold human misery. The work of transferring rust resistance in rice to the other cereals proceeds. Gene transfer will be integral to producing the agricultural productivity gains necessary for feeding a world of 10 billion people.

In addition to improving agricultural production, international species transfer can also benefit the environment by offering alternatives to chemical pest control. The use of predator species to control pest populations is fundamental to biological control, a relatively environmentally friendly practice that uses natural methods to suppress pests. In many cases, predator species are introduced to ecosystems. In other cases, indigenous predator populations are protected to control pest populations. As environmental awareness has grown, demand for chemical-free alternatives to pest control has increased. Alien species can be substitutes to chemical herbicides, fungicides, and pesticides, which can cause wide-ranging changes in eco-systems by affecting nontarget species and polluting water resources. For instance, several parasitoids were successfully introduced in the United States to control the alfalfa weevil, itself an invasive alien species from Europe. Absent biological control, the alfalfa weevil caused damage throughout the United States and induced farmers to spray crops one or more times per year (Stoner 2006). While species introductions can provide a valuable method of pest control, they can also backfire and cause significant damage to ecosystems and native species. In some cases, biological control has led to the extinction of native species, and in at least one case, the extinction of an entire genus (Strong and Pemberton 2000).

Gains from genetic and species transfers are likely to persist, though many of the most beneficial transfers, such as those that have yielded modern agriculture, have already occurred. The persistence of beneficial transfers, however, requires knowledge and proper valuation of biodiversity and potential benefits of its uses. Developing countries that supply organisms for international transfer have not realized much economic gain because such transfers have public-good characteristics. The importation of many seeds or genes, for instance, need occur only once to supply the importing country with an indefinite stock of regenerating biological material. Because of its public-good nature, biodiversity is undervalued by source countries, which are typically unable to capture the full benefit of their preservation effort (Zilberman 1992). Countries like Brazil or Indonesia, for instance, have little incentive to preserve the genetic diversity of their rainforests if economic benefits accrue only to western pharmaceutical companies.

Policy is needed to increase preservation of ecosystems like rainforests, which are home to vast amounts of biological material. It is estimated that biodiversity loss is the largest source of nonclimatic global change and is more costly, at present, than global warming (Mooney and Hobbs 2000). The development of royalty schemes can ensure that source-countries derive economic benefit from resource transfers. However, even *ex post* transfers undervalue resource preservation because they do not recognize the option value of protecting biodiversity for future uses. Zilberman (1992) suggests *ex ante* payments based on option value to provide incentives for source countries to maintain their biological resources. Information about biological resources is seriously lacking and research in this area is underfunded (Meyers 1992). It may be that little can be done to prevent the disappearance of some rainforests, but at least research can document what is likely to be lost and suggest preservation of some key species or products that are likely to have beneficial uses in the future. We suspect considerable benefit can be derived from international cooperation to identify, study, and document biological resources.

Not all species and gene transfers are beneficial and many can be quite costly. Nonnative species are spreading at faster and faster rates, imposing costs on the global economy on the order of $1.4 trillion every year (Pimentel 2002). Despite the increasing rate of invasions, only 10 percent of introduced species will become established, and only 10 percent of those will become pests (Williamson 1996). Regardless, the spread of invasive alien species has altered ecosystems, reduced biodiversity, endangered human health, fouled water sources, destroyed agricultural land, and significantly altered the evolutionary process. These tremendous costs, combined with the fact that an established invasive species can seldom be eliminated and that the extinction of species threatened by invasives is irreversible, make the control of invasive species one of the most critical issues facing the global community. The problem, as we will discuss, is largely an economic one.

The spread of invasive species and the consequent homogenization of the earth's ecosystems are accelerating with the pace of movement of people and commodities across countries. Trade is the primary pathway by which nonnative species are introduced to a region, often accidentally by piggy-backing on traded commodities.

Alien species invasions are typically the unintended consequence of market transactions that fail to consider the cost to society of invasive species introductions. But unlike other externalities economists consider, such as pollution, alien species invasions are self-perpetuating. Once an alien species is established, the individual or firm cannot correct behavior to eliminate or reduce the cost of the externality—the invasion cannot be undone. On the other hand, the external cost of pollution, for instance, can be controlled by the firm through its employment of new technology or reduction of output.

Policy responses can generally be categorized as either controlling invasions or preventing them. Examples of the former include attempts to limit the population of invasive species through pesticides and other means of population control, improving ecosystem resilience, and regulating invasive species uses. Prevention efforts include regulations on ballast water discharges and screening and quarantine of foreign goods at ports of entry. Despite seeming preferable to after-the-fact control of invasions, prevention is often ineffective and costly. It may, for instance, slow the movement of international trade. We turn to a complete consideration of the opportunities for prevention and control in Section 3.

## Section 2: Trade in Environmental Amenities

Given heterogeneity in environmental resources among countries, trade in environmental amenities can be efficient and welfare improving. It can, however, also lead to destruction of resources that are undervalued by the governments controlling them. Thus, much like genetic and biological material transfers, trade in environmental amenities should be regulated to ensure welfare-maximizing outcomes. To some extent, these issues can be addressed by traditional trade models by considering environmental amenities like other traded commodities. However, several issues limit the applicability of traditional trade models in this context. First, many environmental amenities cannot be transported. Second, many are nonmarket goods. They are not bought and sold in a traditional marketplace that determines a price for the amenities. Instead, their values need to be imputed and are typically difficult to ascertain. Third, environmental activities can be associated with externalities that must be internalized to ensure optimal provision.

In the context of traditional trade models, countries with relative advantage in commercial goods may export them and import environmental amenities. As with other commodities, there are gains from trade in environmental goods, but environmental quality may decline in some countries. Relative-advantage considerations suggest that poor countries are more likely to engage in health-risking activities and sacrifice environmental preservation in return for revenue from production. Poor regions may even specialize in providing health-endangering activities. Indeed, the export of environmental bads by developed countries has produced pollution havens in developing countries. The relocation of smokestack industries to poor regions is just one manifestation of this trend that has received considerable attention in public dialogue. Research is needed to determine the implications of these relative advantage considerations on the health of individuals in developing countries and the protection of important environmental resources. This analysis suggests some of the world’s most valuable environmental resources, located in developing countries, may be at risk as trade in environmental amenities continues. It adds urgency to the need for a system to document and value natural resources.

The basic trade model applies to well-defined commodities that are transferable and traded in markets, but environmental amenities are difficult to define and measure. Furthermore, environmental quality, health, and safety are not traded in markets. Environmental quality levels are often enforced by decree, and it is not clear that outcomes are consistent with what the models prescribe. Therefore, while trade theory can provide a general guideline, it is important to realize that we do not yet have effective policy tools to obtain optimal international allocation of environmental resources. Most environmental amenities are regulated and, while their imputed prices can be inferred through existing regulations and behavioral patterns, they cannot be observed directly in markets. Furthermore, some amenities, such as health risks, cannot be exported. This implies, for instance, that the value of a representative individual’s life will not be equal across countries. Some developing countries do not have the mechanisms or resources to assess and regulate health risks and may implicitly allow very risky production procedures.

Global environmental externalities are a source of growing concern. Many times, the environmental activities of a nation are not contained within its political boundaries, but rather confer benefits to or impose costs on other nations or the entire world. Ozone depletion, climate change, and acid rain are three global environmental problems impacted by the decisions of individual countries who do not internalize all of the benefits of cleaning up their production and who do not face all the costs of their pollution. Absent policy intervention, individual countries will not choose the optimal provision of environmental amenities from the standpoint of global social welfare. Critics of globalization claim it weakens national sovereignty, which impedes the ability of countries to establish and enforce their own environmental standards. In this context, however, national sovereignty is not the solution, but rather the problem (Frankel 2003). Consider that a forest-dense country, if permitted to trade in lumber, would choose to over-exploit its forest resources relative to the socially optimal level. Its forest production would impose an external cost on the rest of the world in the form of lost biodiversity and foregone carbon sequestration. Therefore, the international community must develop mechanisms to correct this suboptimal outcome associated with unregulated free trade. While the Kyoto Protocol has attempted to regulate carbon emissions, the challenge is more widespread and requires not just a more effective, but also a broader effort.

Apart from the externalities associated with environmental activities, there are dynamic considerations that may lead countries to value natural resources differently than society. The consumption of natural resources is irreversible in some cases, and in others, it may lead to the depletion of exhaustible stocks. The relative valuation of these amenities consequently must account for present and future values. Standard trade models do not address these dynamic issues and should be extended.

Countries may differ in their abilities to control their resources. Some governments may be corrupt and exploit environmental amenities for their own gain. Others may lack mechanisms to enforce environmental standards and trade restrictions. Smuggling, in this context, is a critical issue in the preservation of natural resources, and we return to this issue in Section 5. Multilateral institutions should develop mechanisms to strengthen enforcement of environmental regulation and trade patterns in weaker countries.

A final issue related to trade and provision of environmental amenities is the growing demand for commodities produced by means that are perceived to offer food safety or environmental benefits. As per capita income rises, environmental protection and food safety become increasingly important to consumers. Today we see demand for organic foods and commodities that minimize environmental impacts. By removing information asymmetries between producers and consumers and permitting the differentiation of products according to production methods, international trade can improve market outcomes and permit efficient signaling of consumer preferences for environmental preservation to producers. A system of product labeling can be efficient and improve environmental outcomes, but it can also be used to discriminate against producers. The development of respected, enforced and nondiscriminatory labeling should be a priority of multilateral institutions. For instance, labels that identify organic, free-range, and lead-free products could create additional markets for goods and help consumers make more informed decisions.

## Section 3: Trade and Regulation of Food Safety and Environmental Quality

The Doha Round is intended to address issues of food safety and the environment. In part, these objectives are necessitated by the development of new technologies, new outbreaks of disease, and consumer concerns. Increasingly, consumers are demanding greater levels of food safety and environmental protection. The growing number of these regulations may be responding to evolving consumer preferences, but they are also prone to political capture and may be used by protectionists to reduce competitive pressure from imports. Policies can potentially be influenced by consumers demanding cheap, safe food and domestic producers concerned about competition and the availability of cheap inputs, as well as exporters, taxpayers, and environmentalists. The principal food safety regulations related to trade concern the attempts of importing countries to reduce the risk of adverse health outcomes to acceptable levels. The most important environmental regulations impacting trade include attempts by importing countries to reduce the risk of alien species invasions and demand higher environmental quality provision in source countries through the use of process and production methods (PPM) standards.

## Food Safety

While not trade measures per se, food safety regulations and standards can significantly impede trade. In part, the growing use of these measures is a response to the rapid increase in scientific and technical knowledge. It is an issue for countries wanting to export food and for WTO members negotiating to expand food trade.

The goal of food policy regulations ought to be the provision, subject to resource constraints, of readily available food with characteristics demanded by consumers in a manner that is minimally distorting (Josling, Roberts, and Orden 2004). There is a strong economic rationale for food safety regulation to respond to market failures, which include, in part, information asymmetries that preclude consumers from making fully informed decisions. Food safety regulations can be aimed at reducing risk of bad health outcomes or ensuring minimum quality. Some regulate the content of food, such as the absence of disease or particular chemicals. Others regulate the production process, mandating rinsing and cleaning or banning the use of chemical pesticides or hormones. From an economic efficiency standpoint, content regulations are considered superior to process regulations. They permit the achievement of desired food outcomes without limiting the freedom of producers to use the most cost-effective processes.

There are a number of mechanisms by which countries regulate their food supplies. Quantity restrictions, including bans, are a severe method and generally favored only if other mechanisms are infeasible because of technical limitations. Technical standards provide conditions that importers must meet to have access to markets. They may include limitations on size and weight of commodities or the use of specified processing technologies. While such standards can be justified on health and safety grounds, they may also be used to shift the comparative costs of producers and thereby discriminate against certain producers, such as those from a particular country. Such discrimination is a clear violation of both the General Agreement on Tariffs and Trade and its successor, the WTO. Finally, regulation can also be classified as information requirements and include mandates that food products disclose certain information, such as the presence of carcinogens or other ingredients deemed hazardous to health. Information requirements may also limit the use of voluntary claims about food products to ensure credible information is conveyed to consumers. Claims of nutritional attributes, for instance, must be substantiated. In response to demand for organic products, many governments have imposed standards with which producers must comply if they are to receive government certification that products are organic.

Despite strong economic justification for regulation of food safety, countries may choose too restrictive or too open food safety laws relative to conditions of optimality. In particular, democratic governments are prone to choosing arbitrarily low levels of risk without weighing the costs and benefits. Governments tend to be afraid of low-probability high-risk events occurring. National governments often adopt a sequential decision-making process that considers first the risk effects of policy and then the costs and benefits. Incremental reductions of risk, therefore, may be favored regardless of the cost to domestic consumers and foreign producers. Regulation may also be used by interest groups to extract rents. Producers may use food regulation to reduce competition from imports. Consumer advocacy groups may use the political process to achieve narrow agendas that are not consistent with welfare maximization. Given that WTO standards for food safety and animal and plant health, the Sanitary and Phytosanitary (SPS) standards, are less transparent than tariffs or quotas, there is ample room for tweaking them to make them stronger than necessary for achieving optimal levels of social protection and to twist the related testing and certification procedures to make competing imports less competitive. The design of mechanisms that reduce the potential for food safety policy to be used for ulterior purposes, like protectionism, is an important element of trade negotiations. It is estimated that in 1995, $2.1 billion of U.S. exports were blocked by animal and plant safety regulations that had little or no merit (Josling, Roberts, and Orden 2004).

**Rent Seeking in Regulation: The Case of Agricultural Biotechnology**

European resistance to genetically-modified organisms (GMO) is a prime example of how food safety concerns can carry the banner for protectionists. The European Union (EU) has banned the importation of food products containing GMO and has also restricted use of genetically-modified (GM) seed by domestic farmers. Europe imposed the restrictions on grounds that the risks of GM technology to human and environmental health are uncertain. However, over the course of more than a decade, and on millions of acres, the technology has proven to be a critical tool for improving agricultural productivity and reducing the use of chemical pesticides. No adverse effects have been documented. The regulations, therefore, seem unjustifiable from the standpoint of protecting human and environmental health.

Regulations are not promulgated in a vacuum. Rather, regulators are influenced by self-interested groups and can be assumed to maximize the weighted well-being of various groups, including consumers, producers, and interest groups. The weights applied to the well-being of each constituency are determined by the rent-seeking activity of the constituencies. In the case of agricultural biotechnology, regulation can be influenced by consumers, farmers, biotechnology firms, producers of competing inputs (such as chemical companies), and environmentalists. Consumer opinions about regulation can be important determinants of promulgated and de facto regulations, but consumer opinions are not formed in a vacuum either. In the case of agricultural biotechnology, they may be influenced by biotechnology firms and farmers who seek to increase revenues by expanding GMO sales and by environmentalists who oppose GMO. Opinions may also be formed on the basis of expert testimony. Scientists, in this context, may either endorse a technology or oppose it depending on how the technology affects their own welfare. In addition to the import of consumer opinion in the political and regulatory processes, consumers also influence retailers, who may impose de facto bans of technology to maximize their welfare.

In the case of GMO, there is evidence to suggest the distinction between regulatory approaches of the United States and EU is not explained entirely by differences in consumer preferences. It is true that European consumers are less trusting of government and more concerned about food safety following lapses in food safety. Furthermore, the support for GMO among European experts is more tepid in the EU than the United States, perhaps because EU scientists did not stand to benefit from agricultural biotechnology like U.S. scientists, whose roles as innovators in the industry made them considerable stakeholders. Still, there is reason to believe European resistance to agricultural biotechnology is the result of rent seeking by other constituencies, namely producers of competing inputs. Intellectual property rights to GM technology are principally owned by U.S. firms like Monsanto and employed by U.S. farmers.

On the other hand, European countries are leaders in the chemical industry, which is hurt by the use of GM crops (Graff and Zilberman 2007).

A nuanced model of rent seeking in the context of regulation suggests political economy and self-interest are responsible for considerably curtailing the market for agricultural biotechnology. The excessive regulation of GMO has been costly. From 1990 to 1998, the agricultural biotechnology sector grew according to data on field trials, regulatory filings, and commercialization of new products. After 1999, however, agricultural biotechnology has withered. Rent seeking from various constituencies produced a heavy regulatory burden at the same time consumer opinions formed by these constituencies led to de facto bans by retailers. The combined effect was to reduce the adoption of existing agricultural biotechnology and reduce the expected returns to innovation.

The net effect of the contraction of agricultural biotechnology is that technologies that may have improved environmental quality indirectly by increasing yield and thus reducing crop acreage have not been introduced. In particular, agricultural biotechnology has not been adopted in Africa, where even the present generation of technologies could have increased food supply. Yield data over the last 10 years suggest that productivity growth is slowing for crops that have not benefited from significant GMO adoption. Yield gains have been persistent for the one crop that has seen widespread use of GMO—cotton. Adoption of existing technology could have mitigated the food crisis that began in 2008 because of high demand for crops for bioenergy and for food to feed a growing world population that demands increasingly land-intensive diets. Given the demands for agriculture to feed and fuel a growing world population, heavy regulation of agricultural biotechnology should be reconsidered.

WTO countries can take legitimate measures to protect the life and health of consumers (as well as animals and plants), but such measures must have scientific justifications and cannot unnecessarily impede trade. Under the WTO's SPS agreement, international standards are the benchmark against which national measures are judged. Standards that impose greater restrictions on imports than the international norms must be justified by science and based on an assessment of risk.

There are notable differences in the economic implications of classic trade barriers, such as tariffs and quantity restrictions, and product standards and regulations. The former are discriminatory border taxes, which generally result in inefficient resource allocations and reduce consumer welfare. By contrast, at least in principle, SPS standards are introduced by the government in the interest of society, to achieve the important social objective of protecting human, animal, and plant health. Food safety is a public good that would not be accounted for in a private market (Kindleberger 1983). Social losses arising from the elimination of food safety regulation could well exceed any associated economic efficiency gains.

The existing framework for guarding against the misuse of safety regulations is deficient in two main respects. First, it lacks a mechanism to develop consensus around the best available science. The best available science may be somewhat uncertain, but the existence of some uncertainty should not justify a precautionary approach that impedes international trade. Countries must be compelled to acknowledge the findings of the scientific community, particularly when research permits a consensus. Second, the current framework lacks an agreed-upon method for risk analysis. In the following section, we introduce a model of risk assessment that should be adopted to ensure acceptable levels of risk are achieved efficiently.

A final issue that warrants attention is that of harmonization. A great deal of discussion in recent trade talks has centered on the extent to which harmonization should be pursued. Harmonization of safety regulations would reduce transactions costs of trade. The existence of a wide range of policy to regulate the same risk raises the costs to producers of doing business with different countries. Harmonization seeks to reduce the variation in policy so different production methods and content requirements for countries do not burden producers. Efficiency of production would be increased through harmonization as it reduces information asymmetries between buyers and sellers and promotes product commutability, thereby allowing for increased economies of scale and scope (Skyes 1995; and Kindleberger 1983).[1] Harmonization would also reduce the potential for food and environmental safety regulations being corrupted by protectionist motives. Harmonization ignores, however, the existence of heterogeneity in factor endowments, conditions, and preferences across countries.

Expanding trade has brought into sharper focus the divergence among countries' food safety regulations and standards. These variations may reflect differences among their populations' tastes and preferences, ability to produce safe food, and willingness to pay for risk-reducing technology. These differences introduce additional uncertainty to the use of food safety standards. From an economic standpoint, to the extent some nations value food safety more than others, it is efficient that they be permitted to demand safer foods, and markets should be permitted to operate. As factor endowments and climatic and political conditions vary, the costs of a given regulation will also vary. Governments should balance these costs against the benefit of regulation. In cases when the costs dominate benefits, the policy should not be pursued. Harmonization in the presence of heterogeneity, therefore, can be considerably distorting.

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[1] For more on the role of the WTO, and its ability to cope with food safety, see Athukorala and Jayasuriya (2003) and Hoekman (2002), among others.

**Environmental Safety**

Nations may attempt to preserve environmental quality at home and abroad by intervening in international trade via two primary mechanisms: enforcing PPM standards and blocking the importation of invasive species. Under existing trade agreements, PPM standards can be used to influence environmental activities in foreign countries and to reduce the effects of global environmental externalities so long as they do not discriminate against particular producers. Intervention throughout the trade system can reduce the risk of species invasion, though it may be combined with monitoring and control of the invaders.

The EU provides a very contemporary example of how PPM standards may be used to affect environmental protection. It is, as of this report, considering a ban on imports of biofuels produced on lands it deems ecologically sensitive. Its aim is to halt or at least slow the conversion of natural habitat to crop production, particularly in Latin America and Asia, where forests are being cleared to plant biofuel feedstock. The proposal would ban biofuel imports produced on land recently converted to productive uses, including those produced in wetlands, swamps, marshes, and grasslands. This proposal provides an example of how environmental concerns have become paramount and absolute in the minds of regulators. It ignores the benefits of biofuel production in terms of increased energy supply and reduced carbon emissions by indiscriminately declaring all unfarmed land important from an environmental perspective. Certainly some lands offer greater benefit in their natural state than in production of energy, but others should be recruited to solving global energy and climate change challenges. This proposal is not an efficient method of correcting externalities, nor is it based on science. It may be the result of political efforts by environmentalists or may be intended as a trade barrier to reduce competition to European biofuel producers, who face higher costs than developing countries. The model introduced in the subsequent section can be used to identify which PPM standards are the result of political economy rather than a rational decision process.

In alien species and disease invasion management, governments seek policies that maximize total social welfare subject to many constraints, including the limited budgets of regulatory and enforcement agencies, the profit-maximizing behavior of importers and growers, and the surplus-maximizing behavior of consumers, market-clearing conditions, as well as political, legal, technological, and information constraints. Policies should seek to balance the use of incentives, monitoring, and control along the species-movement process. The potential for rejection of imports prior to shipment, as well as rejection of imports and the imposition of fines at the border of importing countries provide importers with incentives to ensure their shipments are clean. After alien species have entered the importing country, farmers can be subsidized to detect invasions and protect against them. Monitoring can be done overseas and at the border, as well as within country to detect invasions. Control of invasive species includes treatment of shipments overseas and at the border, as well as chemical spraying to control or eradicate populations within the country. Fig. 1 illustrates the movement of invasive species from the country of origin through the importation process and highlights the opportunities for intervention throughout the process.

Cost-benefit analyses are typically used to determine which projects should be pursued. A project should be undertaken if expected present value of control or environmental project exceeds or equals the expected present value of the cost of the project. A common response by decision-makers to the risk of invasion is to ban imports of any commodity that poses such a risk. Such a response ignores the benefits of imports and invasive species themselves, as well as less blunt policy options that may be available, such as control or financial incentives.

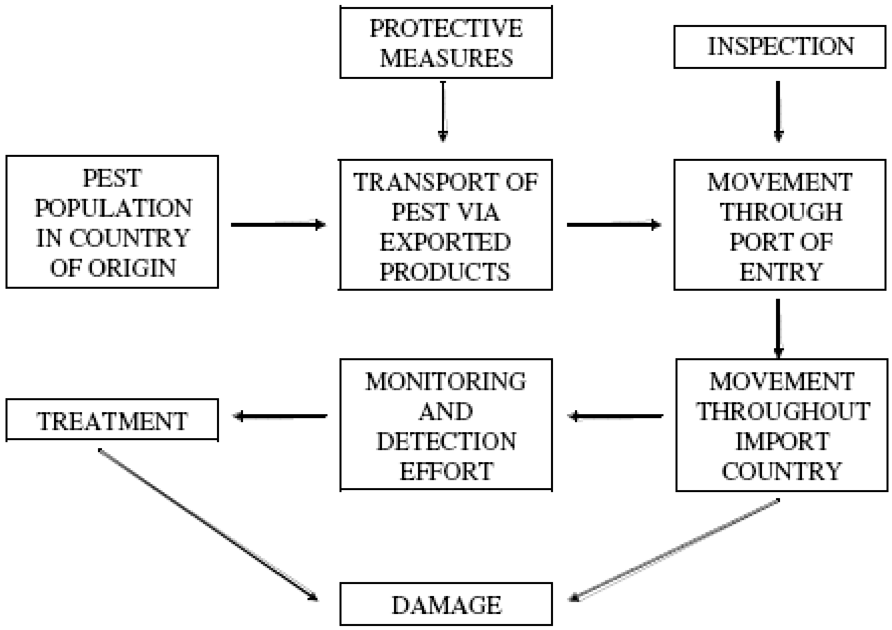


**Fig. 1**. Species population movement process: Driven by biology and economics

The determination of optimal policy response for species invasions is difficult for several reasons, not the least of which is the difficulty of assigning value to nonmarketed environmental services. The challenge of determining the full range of effects of invasions has yet to be overcome in the literature. It is compounded by the diverse effects of invasions on other species and the time-dependent magnitude of effects. Evaluation is further hindered by the endogeneity of control dynamics. Risk of invasion and cost of invasion, for instance, are functions of human impacts on ecosystems and human effort to reduce risk (Dalmazzone 2000). In general, lands altered for agriculture or other uses are more susceptible to invasion and support fast growth of invasive species. Mitigation and adaptation efforts, on the other hand, reduce invasion risk.

Besides the endogeneity of risk, the nature of invasion risk poses additional challenges.

The probability of invasion is typically low, but the consequences of invasion are quite high. A single invasion can be calamitous. The power of expected utility is diminished with low-probability catastrophic events (Chichilinsky 1998). People treat very unlikely events by either overestimating their probabilities of realization or setting their probabilities to zero. Invasions are also one-time events often independent of history, making estimation of probability density functions impossible (Horan et al. 2002).

Because invasion is uncertain and a low-probability event and because prevention efforts do not stop invasions with certainty, it may be preferable to expend limited resources on control of invasions once they occur. In some cases, it may be optimal to undertake considerable control effort as soon as an invasion is detected in the hope of exterminating the invasive species before exponential growth. In other cases, it may be optimal to try to maintain the invasive species population at an acceptable level over an indefinite period of time.

Alien species invasions impose costs not often internalized by those responsible for them, such as importers. Therefore, there is a need for financial incentives that can align private and social costs. Strong property rights and institutions to protect them, as well as liability rules, can help to internalize the externality. Perrings, Dalmazzone, and Williamson (2005) propose importers of potential invaders be required to purchase insurance in case their imports do cause an invasion.

Invasion prevention is a weakest-link public good. Benefits to society of prevention effort are determined by the weakest member of society. An invasion is the result of interactions among countries, including a country that is home to a potential invader and other countries connected to it through trade in goods or people. Efforts to contain or eradicate pests will fail even if all but one member of society does so successfully. This suggests there will be underinvestment in prevention and points to the need for a national policy for prevention and control when invasions occur within borders and an international program for invasive species that cross borders (Perrings, Dalmazzone, and Williamson 2005). The creation of institutions to support the countries least effective at preventing invasions could help to overcome the weakest-link aspect of invasions. An international institution to monitor and report on alien species invasions could coordinate global responses to what is increasingly a global problem.

While economics can address the market failures posed by species invasions, it is important to realize the role of political institutions in determining responses to the problem. Optimal responses to invasion risk may be to increase trade restrictions. Such policies may not be implemented, however, because of political pressures for trade liberalization. In addition, members of society are typically unwilling to support considerable expenditures on prevention when the probability of invasion is low and the costs of invasion are uncertain. Democratic institutions, therefore, can be a contributing factor to underinvestment in prevention and control.

## Section 4: A Model for Risk Assessment

As the foregoing discussion of food safety and environmental regulation elucidates, the development of a coherent method of risk assessment in the presence of uncertainty is important for efficient patterns of trade. Regulatory decisions involve not just managing risk, but managing risk compounded by uncertainty. Furthermore, it is evident that decision makers and the general public are quite sensitive about the relatively unlikely prospects that these risks are large, implying a need for decision methods that explicitly incorporate uncertainty in a practical manner. We proceed in this section by presenting a model that essentially applies a safety rule decision criterion to a probabilistic model of risk generation. It can be used to weigh tradeoffs in the regulation of human health, food safety, and environmental health.

The model presented here is consistent with risk assessment methodologies developed in public health. It measures risk explicitly as the probability of data occurring. Decision-theoretic and economic models, on the other hand, measure risk as the deviations from the norm or average. Before proceeding, we should clarify that risk, in this context, will refer to the probability that an individual selected at random will suffer an adverse health event, such as illness or death. The functions relating risk and the variables that generate it are not known with certainty and are subject to error, the magnitude of which will be measured by uncertainty.

Following the methods of Lichtenberg and Zilberman (1988), we develop a multiplicative risk-generating function that relates relevant activities to health or environmental risk. For instance, one can model the chronic health risks arising from the use of contaminated drinking water as the product of the level of contamination introduced into the environment, the rate at which the contaminant enters the water supply, rates of water consumption, and dose-response rates. It can also model food and environmental safety risk as the product of farm level practices such as pesticide use, the contribution of practices in processing, and the contribution of inspection.

Formally, the health risk of a representative individual, *R*, is the product of the following functions:

(i) $f_1(X_1, \beta_1, \varepsilon_1)$ is the risk contribution of farm-level practices, such as chemical use. For instance, it may relate the level of pesticide residues on apples to pesticides applied by a farmer. $X_1$ is the level of pesticide use, $\beta_1$ is a policy parameter that can be thought of as affecting incentives for damage control activity at the site, and $\varepsilon_1$ is a random disturbance.

(ii) $f_2(X_2, \beta_2, \varepsilon_2)$ is the risk contribution of processing practices, which can include processes that expose food products to additional chemical or disease as well as processes that are risk reducing, such as pasteurization or rinsing. $X_2$ is the level of processing activity and $\beta_2$ is again a government-determined policy parameter that can influence processing decisions, either by direct control or incentives. $\varepsilon_2$ is a random disturbance. This function relates, for instance, pesticide residues on imports to the level of rinsing and the degree of food processing producers undertake.

(iii) $f_3(\beta_3, \varepsilon_3)$ is an inspection contribution function, which is a function of policy, $\beta_3$, and a random element $\varepsilon_3$. It models the effect of import inspection on health outcomes, where it is assumed that with some error, governments can detect and destroy imported commodities or otherwise eliminate health risks.

(iv) $f_4(P, \beta_4, \varepsilon_4)$ is the quantity consumed, where $P$ is price, $\beta_4$ is a policy parameter influencing consumption, and $\varepsilon_4$ is a random element. The product $f_4(\cdot)\, f_3(\cdot)\, f_2(\cdot)\, f_1(\cdot)$ is equal to the overall exposure level of a representative individual and is denoted by $E$. Finally,

(v) $f_5(\beta_5, \varepsilon_5)$ is the dose–response function, which relates health risk to the level of exposure of a given substance. It relates, for instance, the proclivity of contracting cancer to the ingestion of particular levels of chemical. It is based on available medical treatment methods, $\beta_5$, and a random variable, $\varepsilon_5$. Dose–response functions are estimated in epidemiological and toxicological studies of human biology.

In practice, the specification of the risk generation function is based on risk assessment models developed by public health professionals. For example, studies to control cancer risk caused by groundwater contamination have used risk generation models based on the work of Crouch and Wilson (1981), as well as Lichtenberg, Zilberman, and Bogen (1989).

Assume the random elements in each function, $\varepsilon_i$ for $i = \{1,...,5\}$ are distributed log normal and are uncorrelated. Then, the log of health risk *R* is distributed normally with mean equal to $\mu = \sum_i \mu_i$ and variance equal to $\sigma^2 = \sum_i \sigma_i^2$ , where

$$\mu_i = \mathrm{E}\left[ f_i(\cdot) \right] \text{ and } \sigma_i^{\,2} = Var\left[ f_i(\cdot) \right].$$

Both the mean and variance are assumed to be nonincreasing in $\beta = \{\beta_1,...,\beta_5\}$, i.e., $\partial\mu_i / \partial\beta_i \le 0$ and $\partial\sigma_i / \partial\beta_i \le 0$, and the social cost of regulation is assumed to exhibit decreasing marginal productivity, i.e., $\partial^2\mu_i / \partial\beta_i^2 \ge 0$ and $\partial^2\sigma_i / \partial\beta_i^2 \ge 0$ .

Next, if we can estimate the functions $f_1(\cdot)$, $f_2(\cdot)$, $f_3(\cdot)$, $f_4(\cdot)$, and $f_5(\cdot)$, we can determine the optimal combination of pollution control, exposure avoidance, and medical treatment using simple maximization techniques.

The safety rule approach to regulation seeks to limit to some small amount the frequency of violations of a predetermined standard. In the context of health risk regulation, this goal can be expressed as ensuring that the incidence of the relevant adverse health effect (here the log health risk *R*), exceeds some maximum allowable level, denoted $R_0$ , no more than a fraction of the time $1-\alpha$. This can be written formally as

$$\Pr\ (R \ \ge\ R_0)\ \le\ 1\ -\ \alpha. \qquad (1)$$

The regulatory decision problem can therefore be expressed as the choice of a set of optimal policies $\beta$ that minimize total social cost of meeting the safety rule (3):[2]

$$\begin{aligned} &\underset{\beta}{Max} \quad -C(\beta) \\ &s.t. \sum_i \mu_i + F(\alpha)\sqrt{\sum_i \sigma_i^{\,2}} \leq R_0 \end{aligned} . \tag{2}$$

This approach has been used to analyze worker safety by Lichtenberg, Spear, and Zilberman (1993) and by Harper and Zilberman (1992), biotechnology regulations by Lichtenberg (2006), food safety policy by Sunding and Zivin (2000) and Taylor and Hoffman (2001), and waterborne disease control by Zivin and Zilberman (2002), as well as water quality regulation by Lichtenberg, Zilberman, and Bogen (1989), among others.

The solution to this problem is a set of policies $\beta$ that can be characterized in terms of the total cost to society of implementing these policies ($C(\beta)$) in order to achieve a risk standard $R_0$ with a margin of safety $\alpha$. For simplicity, assume $\beta_i$ denotes total social cost of the *i*th regulatory activity. Hence, $C(\beta) = \sum_i \beta_i$ and the necessary conditions for social cost minimization are

$$-\frac{\partial \mu_i}{\partial \beta_i} + \left[\frac{F(\alpha)\sigma}{\beta_i}\right]\tau_i \eta_i \leq \frac{1}{\lambda}, \tag{3}$$

where $\tau_i = \frac{\sigma^2{}_i}{\sigma^2}$ represents the share of uncertainty attributed to the *i*th policy and $\eta_i = \frac{\beta_i}{\sigma_i}\frac{\partial \sigma_i}{\partial \beta_i}$ denotes the elasticity of the standard deviation of the *i*th policy with respect to the *i*th action.

[2] Let *R(α)* denote the level of log risk exceeded with probability *1-α* and *F(α)* denote the value of the standard normal distribution which is exceeded with probability *1-α*. Then, and following Lichtenberg and Zilberman (1988), $\frac{R(\alpha) - \sum_i \mu_i}{\sqrt{\sum_i \sigma_i^{\,2}}} = F(\alpha) \Leftrightarrow R(\alpha) = \sum_i \mu_i + F(\alpha)\sqrt{\sum_i \sigma_i^{\,2}}$ and therefore $R(\alpha) \leq R_0 \Leftrightarrow \sum_i \mu_i + F(\alpha)\sqrt{\sum_i \sigma_i^{\,2}} \leq R_0$.

$\lambda$ represents the shadow price and can also be viewed as the implied value of life (as will be argued below). Such an approach was used, for example, in Lichtenberg, Zilberman, and Bogen (1989), where the regulatory objective was to establish a cost-minimizing water quality standard such that the risk of cancer from chemical residues is at or below an acceptable level with different levels of statistical significance.

The safety approach introduced in the current section assumes two key variables—maximum allowable risk $R_0$ and the marginal level of safety $\alpha$—are given. In reality, both variables are set at the decision process. Choosing the marginal level of safety α is essentially equivalent to setting a confidence level for hypothesis testing and, therefore, is not controversial. As a practical matter, we can simply choose from the levels prevalent in scientific work (e.g., 0.95, 0.99). It might, however, become an instrument for protection if the marginal level of safety is applied at each stage of the risk generation function. For example, if it is applied separately to the production-processing-distribution stages, and if countries agree to $1-\alpha = 0.95$, then the marginal level of safety equals $(1-\alpha)^3 = 0.05^3 \approx 0$. We may, therefore, observe creeping safety (Lichtenberg and Zilberman 1988). Even though there exists international agreement on the marginal level of safety, it may be abused.

The determination of the maximum allowable risk is less straightforward. This parameter is likely to be subject to political debate, and selection of a specific risk standard tends to be a political decision. Since policy analysis, in general, is aimed at choosing standards $(R_0)$, as well as regulatory measures $(\beta)$, it is beneficial to examine together instrument choices and social costs associated with the entire range of feasible standards. In other words, it is useful to derive a trade-off curve between social cost and risk given margin of safety. We call this the Risk-Cost Trade-Off (RCTO) curve.

The RCTO curve can be derived, for a given margin of safety, by solving the cost minimization problem given in equation (1) for every relevant risk standard.[3] Initially, given $R_0$ and $\alpha$, the optimal policy is derived: $\beta^*(R_0,\alpha)$. This solution is then substituted into the objective function to yield $C^*(R_0,\alpha) \equiv C(\beta^*(R_0,\alpha))$. This exercise, done for all plausible values of maximum allowable risk, yields an uncertainty-adjusted cost curve for risk reduction (see Fig. 2). Points above the curve represent inefficient policies used to achieve a given risk standard (see, for instance, point A in Fig. 2).

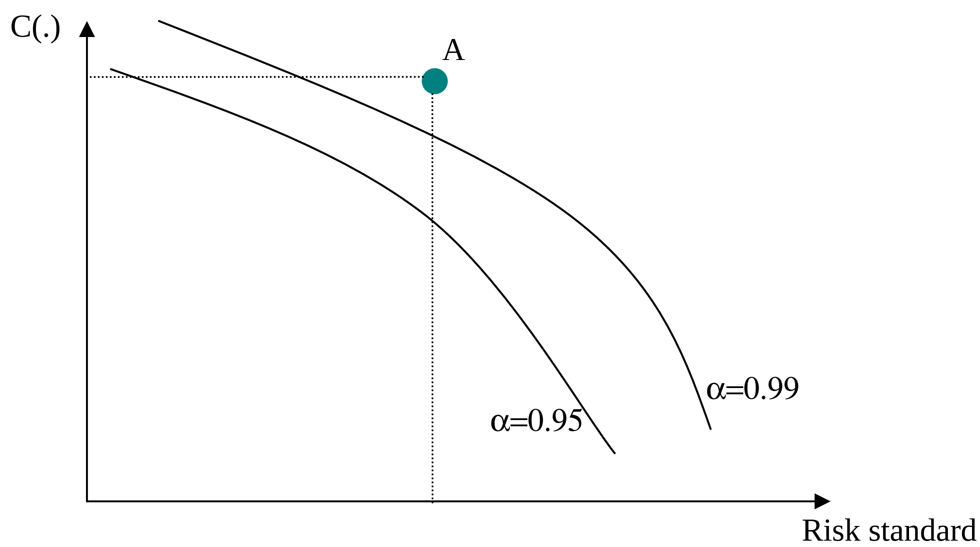


**Fig. 2**. The Risk-Cost Trade-Off curve

[3] A similar curve was derived in Lichtenberg, Zilberman, and Bogen (1989).

It can be shown that regulatory expenditure $C(\cdot)$ decreases (increases) as the level of maximum allowable risk $R_0$ and the margin of safety increase (decrease).[4] These results can be used to show that the RCTO curve is downward sloping in risk standards. Further, the RCTO curve shifts out with higher margins of safety (see Fig. 2). The RCTO curve can, therefore, be used as a decision tool to evaluate and compare standards.

The slope of the RCTO curve, the Lagrange multiplier $\lambda$, represents the marginal cost of risk reduction. This shadow price can be viewed as an estimate of social willingness to pay for risk reduction. Therefore, the multiplier $\lambda$ can be used to construct an uncertainty-adjusted estimate for the value of saving a life. This estimate can be used to enforce consistency in the valuation of a statistical life, since minimizing the cost of reducing risks to human health and safety implies equal marginal cost of risk reduction across sources of risk.

Inconsistency is, however, observed and not owed entirely to political economy. Cropper et al. (1992), for example, show that U.S. Environmental Protection Agency (EPA) decisions are not consistent. The reason is that the implied value of life of a pesticide applicator is approximated at $35 million, whereas the life of a consumer who may be exposed to pesticide residues is valued at only $60,000. The authors attribute these differences to EPA's bias toward reduction of large individual risks. Van Houtven and Cropper (1996) also find evidence that EPA is biased toward minimizing risk for vulnerable populations, as opposed to populations at large. Although inconsistencies may be acceptable, this framework is still useful for screening large biases in the decision process. Moreover, it can be used to better understand the motives of regulators in setting standards.

[4] See also Lichtenberg and Zilberman (1988).

# Section 5: Political, Institutional, and Firm-Level Considerations

### Political and Institutional Response

While science, public health, and statistics establish much of the intellectual foundation for intervention, regulatory measures are the outcome of a bargaining process between the regulator and various interest groups. This political process can affect the margin of safety and the computed benefit from the regulatory measures.

Formally, the political process can be modeled as a cooperative game, à la Harsanyi (1963) and Zusman (1976), or as a noncooperative game, à la Bernheim and Whinston (1986) and Grossman and Helpman (1994). The fundamental assumption guiding both models is that any individual who is affected by government policy has an incentive to influence the policymaker. Food safety regulation affects the regulatory agency, consumers, farmers, the retail food sector, incumbent firms, start-up firms and new entrants, as well as firms in competing sectors. The regulatory measures affect each group differently and, therefore, create different, and in many times opposing, incentives. Competition among groups and their desire to influence decisions and regulatory measures determines the political process by which regulations are promulgated.

For example, the regulatory agency's employees may benefit from more power and, therefore, seek stricter regulation simply because it enables them to get higher income. Consumers, on the other hand, care about their well-being (consumer welfare). In Europe, for example, consumers perceive biotechnology is hazardous to their health. They therefore support the regulatory decision banning imports of transgenic crops to Europe. The production side also faces different, and in many times opposing incentives. Using examples from the biotechnology sector, it can be shown that the first and, even more so, the second generation biotechnology products save production costs and increase yields. Farmers, therefore, should support weaker regulatory measures on biotechnology. The retail food sector wants to minimize its exposure to food safety problems, which leads to negative publicity. Hence, all else being equal, the retail food sector benefits from stricter regulation. The incumbent firms, such as the major biotechnology firms, benefit from barriers to entry and increasing returns to scale. Thus they push for stricter regulations. Firms in competing sectors also benefit from barriers to entry and investment, and therefore join incumbent firms in luring the regulatory agency to set stricter standards. Start-up firms and new entrants, on the other hand, argue for weaker regulatory standards. Finally, environmental groups strive to influence the regulatory agency to set measures that they perceive as beneficial to the environment.

The decision to apply regulatory measures and the incentives of the different groups to influence this decision is not, however, limited to a certain sector. Regulation is determined by a bargaining process, which is political in nature and attempts to incorporate the different factors into the decision process. The challenge is in addressing the different incentives, while not slipping into protectionist policy. In Europe, transgenic crops are banned, although there is not even one example where a transgenic crop became a health problem.

To keep political considerations at bay, and to maximize social welfare (not income of a well-connected sector), a transparent and coherent methodology needs to be developed. The risk assessment model strives to meet this challenge. Harmonizing the methodology used, not the standard levels, given that countries can agree on the model's key parameters, seems to us a more promising approach.

In the context of transgenic crops, Zilberman (2006) argued that a major flaw in the current regulatory process is that each new trait is evaluated separately, without taking into account alternatives. Lichtenberg (2006), on the other hand, argued that uncertainty is the principal cause of concern regarding these crops. This better understanding of policymakers' risk assessment, as well as the understanding that conducting risk assessment and risk-benefit analysis in isolation is sub-optimal, implies that incorporating economics into the risk assessment process is a preferred alternative.

**Firm-Level and Individual Response**

To date, the pest and disease exclusion policies previously discussed have been developed primarily on the basis of scientific risk assessment without economic analysis of the response of importers to border enforcement policies. Existing policies are based on the reasoning that increased enforcement effort will result in higher detection levels or, more specifically, that increased inspection will result in a higher number of interceptions and, in turn, higher compliance. In addition to a deterrence effect under which importers respond to increased enforcement with increased care, importers may respond in ways that yield unintended effects. For example, importers may respond to the increased costs imposed by inspections by choosing not to bring goods into a country, or they may ship a reduced amount. Moreover, different types of firms are likely to respond to enforcement in different ways, affecting socially optimal enforcement and social welfare.

Firms choose which ports to ship to on the basis of heterogeneity in inspection effort and competency. Thus, an increase in enforcement or other costs or a decrease in revenues at a given port will encourage a firm to shift to another port, potentially farther away. A firm may shift to a low-inspection port if the gain outweighs revenue loss. Firms with high initial contamination are less likely to choose ports with high penalties or high treatment costs borne by importers. Increased enforcement at a particular port will lead to separating equilibria in which firms with low profit and high exposure opt not to export at all, while others reduce output or switch to low enforcement ports. Ports may vary in their ease of discovering contaminated commodities. A port may have relative difficulty of discovery, but high inspection levels and still be chosen by a high risk firm.

Port shopping implies that firms consider the costs and benefits associated with location, including such factors as inspection intensity, entry fees, distance to port, market conditions, etc. Different firms will weigh these trade-offs differently; high risk firms are likely to select ports that are perceived to have lax enforcement regimes, perhaps at the expense of greater transportation costs. Low-risk firms are likely to value distance to port of entry.

Trade is, of course, a repeated game. Enforcement agencies could, for instance, target known bad actors for more thorough inspection or higher fees. Additional research should consider the potential for firm-specific enforcement regimes as well as variation in inspection across different types of ports.

As mentioned above, greater enforcement effort or rate of discovery raises the incentive for avoidance, including smuggling of commodities like agricultural products. In particular, increased enforcement impels producers to use the black market. Smuggled goods are not detected at ports of entry and are, therefore, not monitored thereafter. They can lead to dire health and environmental consequences. Devastating species invasions, for instance, are the result of smuggling either of invasive species or of contaminated commodities. Increased enforcement may not result in reduced food and environmental risk if it induces greater illicit trade.

Human behavior should also be factored into to the decision process. Consumers may respond to stricter regulation by taking fewer personal safety measures (a similar effect is also observed in insurance markets). They also react to safety information. Responses will vary by consumer (e.g., Viscusi, Magat, and Huber 1987). Firm behavior should also be factored into the decision process. Melcher (2003), for example, argues that firm compliance with regulatory measures is imperfect. Monsanto and its partners, for example, violated federal regulation by planting transgenic crops 44 times between 1990 and 2001.

The risk assessment model outlined in Section 4 provides a structure that allows incorporation of human behavior. One example is presented in Lichtenberg (2006), who extends the risk assessment model to incorporate firm behavior. Such modifications are straightforward conceptually; a lack of sound empirical work to guide the practitioner makes them difficult to implement.

## Section 6: An Agenda for Trade Talks

International trade has important effects on food safety and environmental preservation that should be taken into account in the Doha Round of trade talks. From the spread of disease and other biological material to the ability of trade partners to influence environmental and food safety practices in source countries, the effects are wide ranging and can be beneficial or quite costly. Food safety and environmental regulation can efficiently solve market imperfections to assure acceptable levels of risk to human health and protect valued natural resources. They can also be used to protect producers from the competitive pressures of trade and thereby distort trade considerably.

We have proposed a framework for efficient regulation of trade with respect to food safety and environmental health risks. Political economy considerations may, however, interfere with the implementation of efficient regulation. It is important, therefore, to identify where the political economy has produced inefficient regulation and to determine who wins and who loses. While the use of uniform standards would preclude the subversion of safety regulations by interest groups, it would also reduce efficiency in the presence of heterogeneity across countries. Rather than requiring all countries to follow the same standards (and in effect value life, safety, and domestic environmental resources equally), we suggest imposing a uniform decision-process for countries to follow. To the extent trading countries can agree on a decision-making process that uses a risk assessment model and the best available science and empirical findings, the capture of food safety and environmental regulation by special interests and protectionists can be mitigated. Where politics is thought to have overcome science, trade organizations should demand to know the decision rules that produced suspect regulation. A decision rule that deviates from a consistent and rational procedure based on the best available science should be easy to identify.

Economics should not be ignored in the promulgation of regulation. Indeed, if it is, then regulation may have effects opposite the intentions of regulators. As we have seen, in certain circumstances, increased enforcement effort does not reduce risk to an importing country and does not induce greater care on the part of exporters. The ways in which institutions, firms, and individuals respond to regulation must enter into the decision-making process. Many of the environmental and human health issues discussed here can be resolved by the development of proper incentives to influence behavior. Countries, for instance, need to be induced to protect the socially optimal level of natural resources, which in many cases are global public goods. If they are not afforded proper incentives, too much biodiversity may be sacrificed for revenue from production.

The political institutions in countries are also subject to rent seeking. Regulators may want greater power derived from a broader regime of regulation. They may be influenced by interest groups. Democratic governments, themselves, may overprotect their food supplies because of fear of low-probability catastrophic events. They may also underinvest in risk-reducing measures if they are perceived to reduce competitiveness in a global economy. Port inspection regimes must consider how firms respond to changes in enforcement—namely, that they will ship to ports that afford them the highest expected profits and that they may reduce output and pre-shipment treatment of commodities amid greater enforcement effort.

The behavior of individuals can also be important. For instance, the delay in detection of alien species invasions can be partially overcome by incentivizing farmers to monitor for invasions. Consumers may respond to stricter regulation by undertaking fewer risk-reducing behaviors themselves. All of these considerations are important and, if ignored, can cause regulation to be counterproductive.

Multilateral institutions like the WTO are important for addressing the environmental and food safety issues considered here. A system for dealing with global public goods must be established. It should be broader and more effective than Kyoto to reflect the fact that global environmental problems extend beyond carbon emissions and also include biodiversity loss as well as other forms of pollution. Protection against species invasions is a weakest link public good, and multilateral institutions should provide support to weaker countries to improve their monitoring and enforcement regimes. Likewise, weak governments may lack the ability to enforce optimizing food safety and environmental regulation. Support from stronger countries can improve welfare in both countries. International support for documenting and valuing natural resources is also urgently needed as higher rates of trade endanger environmental amenities.

Finally, a trusted international food labeling system could permit markets to operate efficiently by providing consumers with choice in terms of the quality and processes and methods of production of commodities they consume.

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