The Political Economy of Biotechnology

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Abstract

The political economy of agricultural biotechnology is addressed in this review through three puzzles. First, why were new crop technologies of the Green Revolution readily accepted, versus today's considerable blockage of genetically engineered crops? Second, why has genetic engineering in medicine and pharmaceuticals been normalized, whereas recombinant DNA technology in agriculture is highly restricted? Finally, why is there greater political acceptance of agricultural biotechnology in some countries versus others, for some crops versus others, and for some crop traits versus others? Explanation requires an extended theoretical framework of regulation that goes beyond a vector sum of weighted material interests. Consideration must also be given to the social construction of risk, political structure, and social psychology. A full political economy of agricultural biotechnology must consider not only costs and benefits to multiple actors in different societies within the classic interest-group and regulator model but also the transnational diffusion of ideologies, with attendant costs to poorer farmers and countries.

1. INTRODUCTION

Agricultural biotechnology is the use of genetic engineering to develop new crops and crop seeds for farmers. Genetically engineered (GE) crops, which are widely referred to as GMOs (genetically modified organisms), trigger political dynamics in ways similar to all new technologies, yet several of the political effects they generate are unusual, distinct, and difficult to explain. All novel technologies engender new material interests for innovators and adopters, plus wider societal questions of aggregate benefit and loss or welfare. The regulation of any technology must be understood as a political process that is shaped by institutions and ideas in addition to material costs and benefits (Graff et al. 2009). A full political economy of agricultural biotechnology must thus consider not only costs and benefits to multiple actors in different societies within the classic interest group and regulator model but also the nonmarket demand for regulation and potential additional costs from nonmarket failure (Kolady & Herring 2014, Wolf 1979).

In this review, we approach the political economy of agricultural biotechnology through three puzzling contrasts. The first is a historical contrast between the enthusiastic political embrace of new crop technologies during the original Green Revolution of the 1960s and 1970s versus the considerable blockage of GE crop technologies today. The second contrast is between today's highly precautionary regulation of biotechnology in farming versus the more permissive regulation of biotechnology in medicine. Although GE farm crops have been stigmatized as "GMOs," recombinant medical drugs have been normalized. The third puzzling contrast is between the greater political acceptance of agricultural biotechnology in some countries versus others, for some crops versus others, and for some crop traits versus others.

In the sections that follow, we examine these contrasts sequentially to develop a preliminary risk–benefit frame for understanding the politics of agricultural biotechnology. We then go beyond material interests to refine this analytical frame by explaining how social constructions of risk from new technologies and politics of regulation vary across different societies and political systems.

In fields involving technical change, Knightian uncertainty is pervasive, making risk–benefit balancing difficult for individuals and societies (Blyth 2002, Knight 1921). This situation is especially prominent in the field of genetic engineering. Risk is indeterminate because there is to date no established hazard from crop biotechnology from which a probability distribution of risk can be constructed. Yet risk is a pervasive theme in politics and regulation of GMOs (Lewontin 2001). Second, there is no way to predict unknown future hazards; risk in this sphere can be socially constructed only in hypothetical or anticipatory terms, generating a distinctive politics of science (Gupta 2011). Even without a new hazard, proving the absence of risk is impossible for science (Giddens 1999). In these circumstances, different interpretations of risk will proliferate and parties will engage in strategic behavior to secure support for the framing of regulatory positions they prefer (Benford & Snow 2000).

Uncertainties surrounding possible risk become less important in politics when wide-ranging social benefits are obvious, as in the case of cell phones. With GE crops, however, most benefits are received by farmers and technology developers, who constitute only a tiny segment of society in today's wealthy countries. Final food consumers in these countries, because they do not get any clear direct benefit, may be turned against GMOs even by undocumented allegations of risk (Agin 2006). Where final users have seen direct benefits, as with GE medical drugs, precaution can be set aside even when risks have been documented through clinical trials. Because citizens typically lack the information and expertise to calibrate risks, they look to governments to determine acceptable risks of technologies and products. Variance in outcomes across countries will therefore also depend on the structure of regulatory institutions and on where the state has located authority to evaluate the science on biotech crops.

Two decades into the era of commercialized GE crops, the political economy of this innovation remains marked by high precaution. Allegations of new risk surrounded the technology from the start and persist today despite absence of scientific documentation. If there has been a regulatory lapse so far, it thus appears to have taken the form of over-regulation rather than under-regulation, reducing potential benefits from the technology (Pray et al. 2005, 2006; Qaim 2009). Explaining this important political outcome must be our principal task.

2. WHY GENETICALLY ENGINEERED FOOD CROPS WERE BLOCKED WHEN GREEN REVOLUTION FOOD CROPS WERE NOT

During the original Green Revolution of the 1960s and 1970s, newly available varieties of wheat and rice—developed through conventional plant breeding, not genetic engineering—were taken up rapidly by farmers large and small, particularly in Asia. Between 1966 and 1998, the percentage of crop area in Asia (including China) planted with modern varieties increased to 82% (Pingali 2012). The improved Green Revolution rice varieties originally developed by the International Rice Research Institute eventually were released in more than 70 countries. By the 1980s, significantly improved varieties of maize, sorghum, millet, barley, and cassava had also been developed. Overall, more than 8,000 new seed varieties were introduced for at least 11 different crops. Counterfactual comparison shows that without these modern varieties, annual crop production in the developing world in 2000 would have been 16–19% lower than it actually was, and world food and feed prices would have been 35–65% higher (Evenson & Gollin 2003).

This rapid uptake of innovative food crops in the Green Revolution stands in sharp contrast to today's nonadoption of most GE food crops. Nearly all biotech crops commercially planted today are intended primarily for industrial purposes or animal feed, not direct consumption as food. In the United States, which has led the GE crop revolution, the three most widely planted GE crops are soybeans, corn (maize), and cotton. Approximately 98% of the soybean meal goes to animal feed, and 88% of the corn is used either for animal feed or as an industrial feedstock for making ethanol. Cotton is a fiber crop, not a food crop.

This is a surprising outcome. Critics have depicted private biotechnology companies as powerful enough to push GE crops into our food supply, but the evidence shows otherwise. Even in the United States, private companies have lost most battles over food crops. GE wheat seeds were first field-tested in the United States in 1994, but in 2004 the agrochemical and agricultural biotechnology corporation Monsanto decided not to market them because activists both at home and abroad had persuaded consumers they might not be safe. Biotech rice has not been commercialized in the United States (or anywhere else) for the same reason. GE potatoes were actually grown on 25,000 acres in the United States and widely consumed between 1999–2001, but cultivation was then voluntarily suspended when foodservice chains told farmers they worried about campaigns portraying their french fries as made of GMOs. GM tomatoes were also cultivated commercially in the United States between 1998 and 2002, but cultivation stopped when consumer anxieties increased. GE melons capable of resisting a virus have been successfully tested in the United States since 1989 but not planted commercially. The only GE fruits and vegetables currently grown in the United States are Hawaiian papaya, summer squash, and a tiny share of sweet corn (James 2014). Ingredients such as soybean oil, corn starch, or corn syrup derived from the processing of GE feed crops are pervasively used by America's processed and packaged food industries, but GE staple food crops, fruits, and vegetables intended for direct human consumption remain largely unplanted, even in the United States.

Beyond the United States, the planting of GE food crops has been blocked not by private initiative but by government policy. Absence of government approval has legally blocked the

planting of GE food crops throughout Central and Latin America. In sub-Saharan Africa, only South Africa allows the cultivation of a GE variety of one food crop, white maize. Until Bangladesh approved transgenic Bt (*Bacillus thuringiensis*) eggplant on a limited scale in 2014, no GE food crops were legal to plant anywhere in South Asia or Southeast Asia. India and Pakistan permit Bt cotton, and the Philippines permits yellow maize for animal feed, but no other GE crops are allowed. China permits cotton, poplar trees, and papaya, but does not yet formally allow farmers to plant GE wheat, rice, corn, or potato. Beyond the Western Hemisphere, few national governments have approved even the planting of GE feed or industrial crops. Only three of the 47 countries of sub-Saharan Africa have made it legal for farmers to plant any GM seeds at all: South Africa, Burkina Faso (cotton only), and Sudan (cotton only). In most African countries, even greenhouse research on biotech crops is not yet legal (James 2014).

Why then has the political economy of GE crops (especially food crops), differed so dramatically from the earlier uptake of Green Revolution food crops? The literature is clear on one point: The blockage of GE food crops does not derive from scientific evidence of new risks. When GE foods and crops were first placed on the market in the 1990s, some scientific bodies, such as the British Medical Association (BMA), refrained from expressing an official opinion. By the early 2000s, however, all the most important science academies around the world, including the BMA, had concluded there was no evidence of any new risk to human health or the environment from any of the GE foods or crops that had been placed on the market up to that point. This remains the official position of the Royal Society in London, BMA, French Academy of Sciences, and German Academies of Science and Humanities, as well as the International Council for Science, Organization for Economic Co-operation and Development in Paris, World Health Organization, and Food and Agriculture Organization of the United Nations (DeFrancesco 2013, Nicolia et al. 2013, Paarlberg 2008). In 2010, the Research Directorate of the European Union reported in an extensive meta-analysis of EU science from more than 150 projects over two decades that "biotechnology, and in particular GMOs, are not per se more risky than e.g., conventional plant breeding technologies" (Eur. Comm. 2010, p. 16).

The greater political resistance to GE crops (compared to Green Revolution crops) emerged not from evidence of new hazards but instead from important changes in historical context. By the time biotech crops were ready to be deployed in the 1990s, elite opinion had become less concerned about food shortages in poor countries: The benefits of GE crops were thus discounted by lack of urgency. In addition, a new structure of transnational resistance to modern farming had emerged, driven by opponents of corporate-led globalization and by advocates for the environment (FOE 2001, Schurman & Kelso 2003, Schurman & Munro 2006, Scoones 2008).

2.1. Neo-Malthusian Anxieties

At the time of the original Green Revolution, potential critics were effectively silenced by a new wave of Malthusian anxiety regarding famine, focused particularly on countries like India. In 1967, William and Paul Paddock (1967) wrote a best seller titled *Famine 1975!* that projected that India would never be able to feed its growing population. Paul R. Ehrlich, an American entomologist, made a parallel Malthusian argument in his own 1968 best seller titled *The Population Bomb* (Ehrlich 1968). Ehrlich predicted that hundreds of millions would die in the 1970s due to excessive population growth.

This Malthusian panic created a strong foundation of political support for the original Green Revolution effort. Donor countries and institutions both in America and Europe provided generous assistance to help countries in Asia import and distribute the new high yielding seeds, produce or import the needed fertilizers, and expand irrigation capacity. The added food production that

quickly resulted from these investments was so gratifying to political elites that Norman Borlaug, the crop scientist who had done the most to develop the new seeds, was awarded the 1970 Nobel Peace Prize.

2.2. The Malthusian Panic Subsides

The perceived urgency of growing more food in the developing world had greatly diminished by the time the first GE crops came along in the 1990s. Between 1980 and 2004, in part thanks to the Green Revolution itself, the prevalence of hunger in Asia declined dramatically. In 1980, 45.4% of Asian children under 5 years of age were technically underweight, but by 2004 that was down to 24.8%. In Latin America the percent of children who were underweight fell from 12.5% to 5.5%. Between 1980 and 2004 the prevalence of underweight children in Africa increased slightly from 23.5% to 24.5%, yet this level of undernutrition was lower than that seen in Asia in the 1960s and 1970s and was viewed as a less urgent crisis (UNICEF 2004).

The diminution of Malthusian fears led to a fateful policy change: Assistance from rich countries to promote agricultural development in poor countries was cut sharply. Between 1980 and 2003, the real dollar value of all bilateral assistance to help modernize agriculture in the developing world declined by 64%, from $5.3 billion (in constant 1999 US dollars) to just $1.9 billion. Between 1980 and 2005, the share of World Bank lending that went to agriculture fell from 30% to just 6%. United States assistance to new agricultural research in Africa declined by 77% between 1980 and 2003, and America's assistance to agriculture overall in Africa declined by 86% (Chic. Counc. 2009).

This withdrawal of public support for agricultural development assistance triggered another important change. The original Green Revolution had been promoted by nonprofit institutions [e.g., philanthropic foundations, donor governments, agricultural ministries, extension agencies, charitable nongovernmental organizations (NGOs)] offering the new seeds free or at cost. When these trusted agencies withdrew from the agricultural development effort after the 1980s, the new GE seeds in the 1990s were left to be promoted by profit-seeking private biotechnology companies. This opened the technology to criticism by activist groups that had begun campaigning in the 1990s against corporate-led globalization (Schurman & Munro 2010, ch. 3).

The anticorporate agenda of activist critics included frightening allegations of health and environmental risks. Mark Lynas, a UK environmental activist who participated in these early anti-GMO campaigns (before deciding in 2013 that they had been damaging and wrongheaded) described the impact: "These fears spread like wildfire, and within a few years GM was essentially banned in Europe, and our worries were exported by NGOs like Greenpeace and Friends of the Earth to Africa, India and the rest of Asia, where GM is still banned today. This was the most successful campaign I have ever been involved with" (Lynas 2013).

As implied by Lynas, the NGO and Transnational Advocacy Network (TAN) campaigns against GE foods were successful in the developing world largely because they were first successful in Europe. The victory in Europe was aided by a legitimate food safety concern that had nothing to do with GMOs. In March 1996, the UK government finally acknowledged the existence of a potentially fatal human food safety risk from eating the meat of animals contaminated from bovine spongiform encephalopathy, or BSE, better known as mad cow disease. Because the government had earlier assured consumers that the meat was perfectly safe to eat, public trust in government regulators was undermined. By coincidence, March 1996 was precisely the month that European officials approved the first import of a GE crop, herbicide-tolerant soybeans from the United States, so activists found it easy to challenge official assurances that this technology was safe. NGOs mobilized street demonstrations and direct actions to block the unloading of ships carrying

GM soybeans (Bernauer & Meins 2003). Not wanting to be targeted by demonstrators, European supermarket chains then began to reject products with GM ingredients as well (Sato 2015).

2.3. Precautionary Regulations Grow and Spread

In June 1997, the European Union responded to pressure from citizens and activists by requiring that all GM food sold there carry an identifying label. Rather than reassuring consumers, this step was taken as further evidence that GM foods must indeed be dangerous: Risk perceptions were thus reinforced by the labeling regulation. By 1998, political anxieties intensified enough to compel EU regulators to place an informal moratorium on new approvals of GE crops.

With this European victory in hand, the advocacy campaign shifted into the global arena through an effort within the 1992 United Nations Convention on Biological Diversity to negotiate a new international protocol (the Cartagena Protocol) governing the transboundary movement of living GMOs (called LMOs). With broad access to protocol negotiations, anti-GM organizations such as Greenpeace, Friends of the Earth International, and the Third World Network promoted a new protocol modeled on the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes. Treating GE seeds like hazardous waste had no scientific justification, but was compatible with views of environmental advocates from Europe who dominated the protocol negotiations; environmental ministries led most negotiating teams. Africans and delegates from developing countries deferred to European opinion (Juma 2016).

Many African delegates originally came to the protocol negotiations not fearing GMOs as dangerous, but worrying instead they might work so well in rich countries as to leave African agriculture further behind. NGOs altered these opinions by warning about alleged risks from GE crops not just to the rich biodiversity of poor countries, but also to traditional agriculture and indigenous peoples (Arts & Mack 2007, p. 53; Pinstrup-Andersen & Schiøler 2000; Schurman & Munro 2010, ch. 6).

The final Cartagena Protocol that emerged in 2000, modeled after the Basel Convention, required that anyone seeking to export living GE seeds must provide a warning label. Moreover, if the seeds were intended to be planted rather than processed or consumed, the exporter would first have to secure the informed consent of an officially designated biosafety authority in the importing country.

Once these precautions were incorporated into a new international treaty, activists began attacking the United States for its longstanding food aid practice of delivering GM corn and soy in bulk shipments. Under the new protocol, kernels of GM corn contained in these shipments were classified as LMOs, meaning the importing country was entitled to a warning label. When the US government resisted this provision, NGOs portrayed unlabeled GM food aid from the United States as part of a stealthy scheme to spread "GMO contamination around the world," which led to a rejection of GM food aid by African countries the following year (FOE 2001, p. 1). Inclusion of rules about LMOs in a global environmental treaty solidified the environmental risk framing of biotech crops. It also selected for a strong say—or veto power—of Ministers of Environment and skewed decisions away from Ministers of Food and Agriculture, or Ministers of Science and Technology, among whom support for new technology was presumptively stronger.

Scholars of international relations initially puzzled over the inability of the United States to block the Cartagena Protocol, given its position as a dominant exporter of GE corn, soy, and cotton. The United States did try to block the protocol but failed when it confronted another major economic power, the European Union, with strongly opposed policy preferences. When major powers disagree over trade standards, the bigger importer is most likely to prevail (Drezner 2007). In commerce, the customer is always right, and Europe was the bigger customer.

The harmonizing of international trade standards is ultimately a political process and not necessarily science based.

2.4. Novel Intellectual Property Concerns

Agricultural biotechnologies also encountered greater resistance than the original Green Revolution seeds because of the stronger intellectual property claims available for GM seeds in some countries by the 1990s. Green Revolution seeds had been developed and delivered prior to the critical US Supreme Court decision of 1980 (*Diamond v. Chakrabarty*) that opened the way for seed patents in the United States. These patent claims fueled fears that if farmers used GE seeds they would have to buy them anew every year, because the traditional option of replanting seeds saved from their own harvest could be a patent rights violation.

This fear was widespread but exaggerated. Patent claims are registered and enforced country by country, and the intellectual property laws of most developing countries did not permit any patents to be registered on seeds; corporate patent claims made in rich countries cannot be extended to most poor countries. In addition to patent fears, critics of GMOs also promoted the idea that the seeds could be sterile due to the presence of so-called Terminator Genes (Herring 2006). Although gene use restriction technologies have been tested in laboratory settings, they have not been used on any field crops; consequently, GE seeds have been just as viable for saving and replanting as the non-GM varieties of the same plants.

Rather than restricting access in poor countries, patent-owning biotechnology companies have frequently offered their proprietary technologies on a royalty-free basis for local use. Examples of this include Monsanto in Kenya in 1991 with a disease-resistant GM sweet potato; Bayer AG, Monsanto, Orynova BV, and Zeneca Mogen BV in 2000 in six Asian countries for high beta-carotene Golden Rice; DuPont/Pioneer in 2005 in Africa for nutritionally enhanced sorghum; and Monsanto in 2008 in Africa for drought-tolerant GM maize. Because of local political resistance and regulatory blockage, none of the above technologies has yet been commercialized, despite this yielding of intellectual property claims. A GM eggplant variety was approved for planting on a limited basis in Bangladesh in 2015, using a gene donated by the private sector but then developed by public-sector and university scientists (Kolady & Lesser 2008). Humanitarian projects and university-based nonprofit technologies also have made appearances (Davidson 2008, Lybbert 2003). Nonetheless, perceived risks to farmers and national food systems from corporate patent dominance contributed to the mobilization against GM crops in developing countries (Charles 2001, Kloppenburg 2004, Kloppenburg & Kleinman 1987). Public-sector and donated technologies, including Golden Rice, were constructed as Trojan Horses or "gateway drugs" designed to facilitate corporate penetration of agriculture for other GE crops (Pringle 2005, ch. 2).

2.5. Rapid Uptake When Regulatory Blockage Is Removed

In those few instances when developing country governments have given farmers permission to plant GE seeds, they have been taken up rapidly. In 2001, South Africa made it legal for farmers to grown GE white maize; within a decade, 72% of all white maize grown in the country was genetically modified. In 2002, the Government of India officially gave farmers permission to plant Bt cotton, and 88% of all cotton area in the country was planted with legally authorized Bt hybrids by 2011, increasing to well over 90% by 2014; unauthorized gray-market Bt hybrids have also been available to farmers at lower prices (Herring 2015). In 2003, Brazil finally gave farmers permission to plant GE soybeans (already widely growing illegally); by 2011, 83% of Brazil's crop was GE. Also in 2003, the Philippines allowed farmers to plant GE yellow maize, and 64% of yellow

maize area was GE just eight years later. In 2006, China permitted farmers to grow GE papaya, and 99% of papaya grown was genetically engineered just five years later. In 2008, Burkina Faso allowed planting of Bt cotton, and within three years the Bt cotton share had increased to 58% (James 2011).

This pattern of rapid adoption indicates that farmers find great utility in GE seeds. This is further buttressed by the fact that farmers sometimes take significant risks to obtain, distribute, and grow GE seeds illegally (Gupta & Chandak 2005, Herring & Kandlikar 2009). Given this utility for farmers and an absence of documented risk, why have national regulatory structures restricted biotechnology in agriculture so much more than in medicine? Also, why is this difference more pronounced in some countries than in others, with some agricultural crops more than others, and with some transgenic crop traits more than others?

3. WHY REGULATION RESTRICTS BIOTECHNOLOGY MORE IN AGRICULTURE THAN IN MEDICINE

Genetic engineering has been widely used in commercial medicine since 1982, when the US Food and Drug Administration (FDA) approved the first bioengineered drug. This recombinant form of human insulin was created by inserting the appropriate human gene into a bacterium, which then manufactured the insulin as it grew. The first recombinant vaccine was approved in 1986, and by 2006 the FDA had approved more than 130 recombinant drugs and vaccines for human use. Europe took the same road, with the European Medicines Agency approving 87 recombinant therapeutic proteins by 2006 (Paarlberg 2008). In Europe as well as the United States, citizens have supported the use of modern biotechnology in medicine far more than in agriculture (Eurobarometer 2010, Priest et al. 2003). Europe even institutionalized the difference with a color code that distinguished "red" biotechnologies in medicine from "green" biotechnologies in agriculture (Falkner 2006).

This split in opinion toward medical versus agricultural biotechnology sharpens our understanding of why GE crops are unpopular. The reason cannot be poor public understanding of recombinant DNA (rDNA) science, as the science of recombinant drugs is just as mysterious to ordinary citizens as that of GE crops. Nor can corporate control be the dominant issue, as the market for recombinant medical drugs has been just as corporate-led as the market for GM seeds. Similarly, high product costs cannot be the issue, because recombinant drugs are of course far more expensive than GM seeds. Nor can the greater dependability of regulations explain strong support for recombinant drugs versus GE crops, because drug regulators have made tragic errors over the years; hasty approvals given in Europe in the 1950s for a morning-sickness drug named thalidomide, for example, triggered thousands of birth defects in children (Marris 2001).

3.1. Involuntary Exposure and Environmental Release

Recombinant drugs receive greater support than GE crops partly because there is less chance of involuntary exposure, and also no environmental release. Risk theorists know that public acceptance becomes less likely when personal exposure to a suspected risk is perceived as involuntary (Fife-Schaw & Rowe 2000). Exposure to recombinant drugs is something the individual can control, because they are doctor-prescribed and always labeled, in contrast to the first generation of GE foods, which were introduced into supermarkets without labels. Commercial recombinant drugs are also produced inside laboratories under tight biosafety control, whereas GE crops are grown in fields without containment, creating environmental exposure for people plus other animal and plant species as well. Europe began to require labels for foods with GM ingredients in 1997, which

eliminated the risk of involuntary consumer exposure, yet by then the technology had been so stigmatized that consumer resistance did not diminish (Eurobarometer 2010, GMO Compass 2006).

3.2. The Importance of Benefits to Balance Risks

The politics of agricultural biotechnology generated a pervasive discourse of risk; the power of this discourse lies in the restricted range of counter-balancing benefits to final food consumers. Biotechnology in medicine differs by providing a wide range of benefits to final drug users. Benefits, then, can be more important than risks. As Helge Torgersen (2000, p. 6) points out, "Medical applications with substantial benefits get support despite some risk, but GM crops lack support even if risks are low."

This outcome reverses the assumption that modern societies will be "risk" societies in which the prospect of loss has become more salient than any prospect of added benefit, thus reducing social enthusiasm for further modernization (Beck 1992). Further modernization has been welcomed in the case of recombinant drugs despite the risks, because ordinary citizens can receive new benefits. In contrast, GE crops are out of favor in rich countries, despite an absence of documented risks, because there are so few visible benefits to ordinary citizens.

The first generation of GE crops introduced in the 1990s carried traits for herbicide tolerance and insect resistance designed to solve weed and pest control problems for farmers, but these traits provided no new benefits to consumers. These crops did not taste any better, look any better, or deliver better nutrition. They brought a significant reduction in on-farm production costs, which explains why growers favored them almost immediately. However, in rich countries on-farm production costs are only about 15% of the final cost of food to consumers, the other 85% being generated by storage, transport, processing, packaging, and advertising (USDA 2013). Early studies demonstrated that in the United States, nearly all of the economic gains from GE crops were captured upstream by farmers, seed companies, and patent-holding innovators, with only 9–10% of the total economic surplus benefitting downstream purchasers (Falck-Zapeda et al. 2000). More recent studies by Qaim (2009) and Bennet et al. (2013) have shown larger shares of benefit going to consumers as rates of adoption increased.

For some organized critics, this absence of new benefits to the final consumer was more important originally than the possible introduction of new risks. In 2001, Margaret Mellon, director of the agricultural and biotechnology program of the Union of Concerned Scientists, explained why her organization supported biotechnology in medicine but not in agriculture: "The therapeutic benefits of the new drugs outweigh the risks, and often there aren't any alternatives . . . Agriculture isn't like medicine. We in the U.S. produce far more food than we need . . . The notion that consumers in the U.S. fundamentally need new biotechnology foods isn't persuasive" (Mellon 2001, p. 64).

Calculations of consumer versus producer benefit are especially salient in rich countries, where food-producing farmers are such a small share of the total population. But why then have governments in heavily agricultural countries also blocked the uptake of GM crops? We turn next to variations in the uptake of GMOs by country, crop, and trait.

4. EXPLAINING VARIATIONS IN UPTAKE

4.1. Variations by Country

GE regulations and crop uptake differ among countries, sometimes even where consumer opinions are not so different, as between the United States and Europe (Vigani & Olper 2013). A 2003

survey by the Food Policy Institute at Rutgers University found that fewer than half (45%) of Americans felt it was safe to consume GMOs, and more than half (54%) felt that "GMO food threatens the natural order of things." More than 60% felt that "serious accidents involving GM foods are bound to happen" (Hallman et al. 2003, p. 11), and more than 90% of Americans have favored, in principle, mandatory labels on GM foods (Hallman et al. 2003). Yet regulations in the United States have been far less restrictive than in Europe.

In the United States, under a 1986 Coordinated Framework for the Regulation of Biotechnology, GMOs are not considered or treated differently for regulatory purposes compared to conventionally developed products. In contrast, the European Union promulgated in 1990 Directive 90/220/EEC that established a separate and more precautionary standard for regulating deliberate release of GMOs into the environment. When citizen concerns increased, Europe's regulations were tightened. In 1997 the European Union introduced a mandatory labeling system, something the United States has yet to do, and in 1998 the European Union suspended all new approvals of GMOs. It then established, in 2004, a more comprehensive requirement not only for the labeling of GMOs, but also for continuous record keeping to trace their presence in the marketplace. Food companies in Europe responded by reformulating their products to eliminate any GM ingredients, so they could avoid both the tracing burdens and the stigmatizing labels (Levidow & Bijman 2002).

Multiple explanations are offered for why the regulatory response in Europe was more restrictive than that of the United States (Schurman 2004). Agricultural economists argue that farm lobbies were more prone to defend GM crops in the United States because the first GM crops—soybeans and corn—were far more widely grown there compared to Europe (Anderson & Jackson 2003). Others point to the larger presence and greater influence in Europe of an incumbent agricultural chemical industry, threatened by GE crop innovations that would require less chemical use (Graff et al. 2009, Juma 2016). Others have stressed the greater responsiveness of governments in Europe to consumer attitudes and expectations (Bernauer & Meins 2003). Differences between political cultures in the United States and Europe have also been highlighted (Jasanoff 2005, Sato 2015). Legal and political differences are important as well (Wesseler & Kalaitzandonakes 2011). In Europe, where litigation is not as easily undertaken or as widely practiced as in the United States, public safety is more likely to be guarded by regulatory systems set in place before the fact, versus class action lawsuits after the fact (McCarthy et al. 2007). Also in Europe, multiparty political systems have given Green Party candidates—who oppose GM crops—a larger opportunity to gain seats in national parliaments or even control environment ministries inside national governing coalitions; there are hence more veto points and veto players.

These differences in GMO regulation between the United States and Europe generate larger global consequences. International relations theorists have shown that regulatory disagreements between major economic powers tend to generate parallel sets of rival standards among the lesser economic powers (Drezner 2007). In the case of GMO regulations, lesser powers enjoying closer commercial or postcolonial ties to Europe (states in Africa, the Middle East, South and Southeast Asia) have predictably adopted the more precautionary European approach (Novy et al. 2011). Countries with closer ties to the United States, including most in the Western Hemisphere plus the Philippines (a former US colony in Southeast Asia), have generally adopted a less precautionary approach (Paarlberg 2001).

With 87% of the total hectares planted to GM crops in 2013 located either in the Western Hemisphere or the Philippines, an American sphere of influence appears to operate (Paarlberg 2008). Of the top 12 countries planting GM crops, eight were either Western Hemisphere countries or the Philippines (in sequence, these were the United States, Brazil, Argentina, Canada, Paraguay, Uruguay, Bolivia, and Philippines). Meanwhile, Europe's more precautionary approach

is extended through trade ties and European-based TANs. States that export food to Europe often wish to remain GMO free, to avoid losing commercial sales and to avoid criticism and stigmatization from European-based global NGOs.

4.2. Variations by Crop and Crop Trait

The GM crops that first came onto the commercial market in the mid-1990s were soybeans, yellow maize, and cotton intended primarily for animal feed or industrial use, not food. The novel traits engineered into these crops helped farmers protect against weeds, crop disease, or insects, but provided no clear benefit to food consumers. As a result, this first generation of GM crops (especially Bt cotton, Bt yellow maize, and Roundup Ready soybeans) enjoyed a distinctly narrow base of loyal supporters: the farmers planting these specific crops; the livestock, textile, and biofuels industries; and the patent-holding technology developers. This base of support was weakest in the countries that did not grow these crops (e.g., most of Europe), did not import livestock feed (many poor countries), did not operate a large textile industry, or did not have a competitive biotechnology industry. The fact that China and India both have large textile sectors helps explain why Bt cotton was officially approved and extensively adopted in these countries.

This first generation of crops and traits helped to contain feed costs for livestock producers and raw material costs for the textile industry, but the final consumers of meat and textile products could discern no direct gain. Because food consumers saw no direct benefit from this first generation of GMOs, the critics were able to stigmatize herbicide-tolerant crops as products of corporate greed that were potentially dangerous to the environment. The chemical-resistance trait engineered into Roundup Ready soybeans encouraged increased use of an herbicide produced and sold by the same company—Monsanto—that produced and sold the seed.

As a counterfactual thought experiment, if the first GM crops on the market had carried traits beneficial to food consumers directly, would activists have found it more difficult to stigmatize the technology? Possibly, yet in the rich and well-fed countries that dominate global opinion formation, virtually all of the nutrient traits needed by consumers are already available in abundance without GE foods. Consumers in rich countries do not suffer from vitamin A deficiencies (e.g., prevalence among US residents is 0.5%) and therefore do not need a GE crop such as high-beta-carotene Golden Rice. When Golden Rice was first developed in 1999 for use in countries with serious vitamin A deficiencies, it was dismissed by activists almost as vigorously as other GE crops. As for GMOs engineered to contain medicines (so-called nutraceutical crops), consumers in rich countries prefer to get needed medical drugs through pharmacies, prescribed in precise doses by trusted physicians, rather than from supermarkets.

It is likewise not certain that critics will be quieted by the emergence of a third generation of GM crops with traits to protect against abiotic stresses, such as drought, flood, heat, or salt. Climate change may increase the need for such crops, yet even farmers can have trouble noticing the benefits of such traits, which produce no gains in the absence of stress. The dominant political narratives surrounding GMOs have never been based on specific traits but on the rDNA crop transformation process itself (Herring 2008, Paarlberg 2008).

5. TOWARD AN EXTENDED THEORY OF GMO REGULATION

Much of the variance in commercialization and uptake across countries and crops is caused by differences in regulation, not market demand. How can we understand this variance in regulation theoretically?

In a basic economist's model of regulating technological change, preferences for more or less restriction are derived from material interests (Graff et al. 2009). Farmers have an interest in agronomic productivity, whereas consumers have interests in taste, safety, and cost, though in rich countries only a small part of the final cost of food to consumers will be traceable to farm operations. Innovator firms have interests in new proprietary techniques, whereas firms selling incumbent technologies resist change. In the standard model, these interests are conceptualized as confronting a regulator (e.g., government) that weighs interests and risks and uses a society-wide utilitarian calculus to decide among alternative regulatory policies.

In this approach, if regulations in Europe are more stifling than in the United States, the explanation must lie in Europe's different constellation of material interests. For example, these interests include fewer competitive farmers seeking market gains by cutting production costs for cotton, yellow maize, and soybeans and more environmental activists, organized organic producers, and large incumbent agrochemical firms facing a loss of sales if insect-resistant Bt crops and glyphosate-resistant crops penetrate the European market.

This focus on material costs and benefits sidelines differences in political institutions, political cultures, or the psychology of risk. It also fails to capture, for developing countries in particular, the cross-border influence of multinational firms, TANs, or intergovernmental organizations such as the United Nations Environment Programme. An extended theory of GMO regulation would add these components to the basic materialist starting point.

The first modification required is a recharacterization of the political role of food consumers in rich countries. In well-fed rich countries, the material needs of food consumers have largely been met, so nonmaterial considerations often loom large. Risk narratives can be more salient, particularly in Europe due to a more turbulent and violent twentieth-century history. Egregious failures of state regulatory science in Europe—thalidomide, nuclear power, dioxin, and transfused blood—contribute to skepticism about official claims of GMO safety (Jasanoff 2005, Lynch & Vogel 2001, Schurman 2004). The science of GE crops is less well understood in Europe compared to the United States, opening still more space for risk narratives (Paarlberg 2008).

Regulation of GE crops in the more restrictive parts of the globe deviates from the model of measurable acceptable risk and adopts instead a standard of precautionary or anticipatory (i.e., hypothetical) risk derived from a social construction of uncertainty (Shah 2011). In this approach, there exists no possible evidence that would establish the safety of GE crops (DeFrancesco 2013, Giddens 1999). At the extreme end of the precautionary continuum, it would be impossible to introduce any novel crop because any uncertainty would constitute risk, triggering precautionary treatment.

Precautionary dispositions will be particularly strong in regions, such as Western Europe, where mistrust of both scientists and private corporations is strong. Not only is there a history of regulatory failure, but deeper cultural differences reinforce a precautionary politics. When asked in surveys if "the benefits of scientific research have outweighed the harmful results," 69% of Americans say yes, as opposed to only 46% of Europeans (NSF 2012). When asked if a free market system is the best system, 37% of Americans "agreed strongly" with that view, compared to only 19% in the United Kingdom, and just 6% in France (Globescan 2011). Responses to uncertainty also differ across countries. Surveys confirm that Americans feel less need to avoid uncertainty compared to Europeans. The "uncertainty avoidance" score for Americans is only 46, compared to 65 for Germans, 86 for the French, and 92 for the Japanese (Hofstede 2001). Because science can never reduce uncertainty to zero, cultural differences such as these can alter regulatory responses to new food technologies.

Institutional differences can also influence regulatory outcomes. The regulator is, for example, not necessarily responsive to inchoate public opinion, nor are interests weighted equally. Rather,

decisions are reached in insulated institutions that differ cross-nationally. The partisan composition of government matters as well. For example, Bäck et al. (2015) show that the presence of Christian Democrats in European cabinets, especially if they control the environment ministry, is associated with more restrictive biotech policy compared to other configurations. Ministers of Environment have different constituencies than Ministers of Agriculture, as well as a stronger mandate to avoid risk than to pursue benefits, resulting in divergent weighting of societal interests by the regulator. As noted, Europe's multiparty political systems are more likely to provide options for green parties to join governing coalitions and thus to influence environment ministries.

Therefore, the standard model presents several challenges in explaining differences in biotechnology outcomes. Public opinion varies, clustering around low information and pervasive risk anxiety. The interagency committees that give regulatory approval for new GE crops will in some countries be chaired by environmental ministers and staffed by environmental ministry officials, leading to more precautionary outcomes. In other cases they will be chaired by agricultural ministers, leading to more permissive outcomes (Paarlberg 2001). This proposition is illustrated by divergent outcomes in South Asia for the same crop utilizing the same transgene for the same trait: the approval of Bt eggplant in Bangladesh versus rejection in India, as explained below (Choudhary et al. 2014, Meherunnahar & Paul 2009, Rao 2010).

Outcomes in more agrarian countries may be shaped by a particular political economy of mobilization as well. Urban groups with transnational resources find it easier to express interests compared to farmers who face severe collective action problems and fewer resources (Bates 1984). Access to transnational resources for urban groups in developing countries may depend upon adopting the anti-GMO preferences of urban elites in wealthy countries, as well as elite preferences about developmental projects planned in those countries. To summarize, standard theory needs to recognize the variability of the regulator and the indeterminate interpretation of risks and benefits, especially in political spaces characterized by low information and replete with assertions specifically designed to create or exploit anxiety.

Once interests are recognized, differentials in collective action determine the effectiveness of pressure on the regulator. The strong pressure felt by regulators to constrain the use of GE seeds then goes well beyond material interests. The great success of anti-GMO mobilization has been to construct a risk narrative of threatened common interests (e.g., safety, environment), based on a discourse of corporate dominance and exploitation (Glover 2010, Schurman 2004, Scoones 2008), leading to empowerment of regulators with precautionary logic (Klumper & Qaim 2014). Farmers, on the other hand, will try to retain a benefit once they have experienced it, but these interest-based efforts may remain dormant if precautionary regulations have prevented GE crops from being planted in the first place. Moreover, collective action difficulties in rural areas compared to urban are well known to skew political dynamics against the interests of farmers.

6. APPLICATION OF THE EXTENDED FRAMEWORK

We can illustrate our amended framework for a theory of biotech regulation by evaluating two comparative cases of insect-resistant crops in India: Bt cotton and Bt eggplant. The first crop was successful and spread to virtually universal adoption by farmers once the regulator approved the Bt hybrids for planting in 2002. The second Bt crop was blocked and put under indefinite moratorium in 2010 (Kolady & Herring 2014, MOEF 2010, Rao 2010). Because the same regulatory system confronted both crops, and the transgene (*cry1Ac*) conferring the novel trait was identical, the comparison allows us to illustrate the politics of regulating food crops (eggplant) versus industrial crops (cotton). These cases also illustrate nonmarket failure in regulation, social mobilization of risk, the role of TANs, and exclusion of farmer benefits from the political process.

Similar to China at about the same time, India supported Bt biotechnology for the well-established benefits: reduction in insecticide applications, better pest control, higher harvestable yield, and improved farmer income. The substantial benefits to farmers in India were indicated by the illicit adoption of Bt cotton hybrids even before official commercialization and by the subsequent rapid diffusion of both official and illegal Bt hybrids (Jayaraman 2001). Nevertheless, political mobilization in concert with active TANs alleged a failure for Bt cotton, spread a farmer suicide narrative, and revived lingering anxieties about a nonexistent "terminator technology" that would produce corporate dominance. The campaign gained great international attention and reinforced opposition to biotech crops beyond as well as within India (Assayag 2005, Herring & Rao 2012, Stone 2012). These campaigns did not spring from substantial material interests and certainly not from the material interests of farmers, as amply demonstrated in numerous field studies and meta-analyses (Kathage & Qaim 2012, Rao 2013, Rao & Dev 2010).

Because the *cry1Ac* gene for insect resistance had proved effective and safe in Bt cotton, application to a popular vegetable crop—eggplant (aubergine or brinjal)—seemed an obvious next step (Kolady & Lesser 2008). Damage to brinjal by Lepidopteran pests (e.g., moth larvae) was extensive and was not controlled by conventional pesticides even at great cost to farmers and some risk to consumers. The scientific regulator by statute in India was the Genetic Engineering Approval Committee (GEAC), the apex body for scientific vetting of GE crops. After nine years of tests involving seven government agencies and departments, the GEAC approved release of Bt brinjal by both the private- and public-sector developers. GEAC's review of the science had concluded that the risk profile of Bt crops was lower than the demonstrated hazards incurred by existing practices of heavy and ineffective pesticide use (Choudhary & Gaur 2008, MOEF 2009).

Extensively documented evidence of material benefits to farmers, increased food safety for consumers, and reduction of environmental hazards from insecticides did not lead to adoption and commercialization of Bt eggplant, however. Instead, a risk discourse around "poison" and environmental harm was constructed, altering the balance of forces visible to politicians (Herring 2015). A similar risk narrative about Bt cotton had been constructed by advocacy groups, alleging multiple undocumented risks and economic failures, including an epidemic of farmer suicides, but it did not stop the crop's spread. The campaign against Bt cotton lacked empirical support and failed to overcome economic interests of farmers, who adopted the technology widely and quickly (Gruère & Sengupta 2011, Kloor 2014, Subramanian & Qaim 2009).

In contrast, Bt eggplant presented a more capacious opening for risk politics. Food crops are inherently susceptible to anxiety framings of importance to consumers (Chassy 2015, Food Safety Magazine 2015, Sato 2015). The insecticidal protein produced by the *cry1Ac* transgene was characterized by critics as a generic toxin or poison to suggest that humans would be harmed just like the insect larvae. No credible scientific evidence of harm to humans existed, but the Minister of Environment held that his uncertainty in this case was equivalent to an unacceptable societal risk. That a Minister of Environment had the decisive voice on food safety was a function of regulatory structure: India's GEAC was constituted under an environmental protection act, in accordance with Cartagena Protocol logic, giving the environment minister de facto veto power over the scientific regulator.

Feared corporate dominance figured in the rejection of Bt eggplant as well. In postcolonial India, the perceived risk of foreign corporate dominance is politically potent. Operation Cremate Monsanto failed, however, because farmer interests in benefits overcame these objections; they adopted Bt cotton rapidly. For Bt brinjal, corporate dominance should have been a smaller concern, as the public–private partnership formed to develop the crop planned to release more varieties from the public sector than hybrids from Monsanto's private-sector partner Mahyco (Krishna

& Qaim 2007). Nevertheless, the Minister of Environment explicitly mentioned public worries about the domination of India's food supply by Monsanto (MOEF 2010, Rao 2010).

Regulatory prospects for Bt brinjal compared to Bt cotton were also diminished by the political economy of beneficiaries. India's eggplant farmers are few and scattered, were not mobilized, had no organization, and had no vertical integration in the national economy; this is in marked contrast to cotton farmers. Their material interests did not enter the calculations of the regulator (Herring 2015). Public consultations were held, but only in seven cities, where urban opposition was easily mobilized, and farmers were largely absent.

The Indian cabinet split on this decision, blocking approval of Bt eggplant (Jayaraman 2010). The Ministers of Agriculture and Science and Technology and indeed the Prime Minister were convinced by the scientific regulator's consensus, but statutory authority lay with the Minister of Environment. Counter-mobilization of scientists was extensive, internationally as well as domestically, but it was politically ineffectual. The structure of regulatory authority in India thus enabled a single veto player (Tsebelis 2002); the regulator's stance was explicitly precautionary and decisive.

To summarize on a normative note, the restriction of innovation on a precautionary basis, when every test for new risks has found none, is difficult to justify in terms of public goods provision. The literature on the political economy of GE crops generally, and Bt crops in India specifically, indicates large benefits for farmers and the environment (Klumper & Qaim 2014, Qaim 2009, Rao & Dev 2010, Zilberman et al. 2007). Restiction of benefits based on hypothetical risk alone can thus be viewed as a nonmarket failure (Wolf 1979). If regulators in India had followed a weighting of measured benefits and scientifically established risks, the GEAC approval would have prevailed and Bt eggplant would have been released, as later happened in neighboring Bangladesh (Choudhary et al. 2014).

7. CONCLUSIONS

The standard political economy model of regulators determining policy by responding to a vector sum of diverse material interests weighted by influence needs modification in the field of biotechnology. Framed collectively as GMOs, these new crops carry a special burden of proof because of the technology used. They must seek case-by-case regulatory approval before any public use, usually in a social void where experience-based farmer or citizen opinion is largely absent. The resulting complexity of interest identification and interest group formation—and consequent collective action—make problematic any deduction of outcomes from structure, that is, material circumstances, alone (Oates & Portney 2003). The framing of rDNA in agriculture, alone among rDNA technologies and alone among agricultural technologies of plant genome modification, has recast uncertainties as risks, despite the absence of evidence of any resultant hazard or incremental risk in comparison with other plant-breeding technologies. Diffusion and acceptance of rDNA crops has consequently been slowed not by market forces but by nonmarket interventions.

The theoretical consequence is that ideas about GMOs matter much more than is typically assumed by a standard political economy based on material interests (Blyth 2002, 2003). Ideas about GMOs also matter more than general principles regarding precaution, as we see these principles applied selectively only to crop biotechnology. The entity being regulated (a GMO) is a social construct with arbitrary boundaries (Batista et al. 2008). The ideas of multidimensional risk used to legitimate special surveillance and regulation of GMOs are promulgated by political use of resonant framing linking biotech to corporate control, hubristic science, and irreversible genetic pollution. TANs find political opportunity in these rich discursive materials. They are especially effective in institutions with regulatory choke points where they have access to veto players they

can find or create inside governmental systems via specialized skills and connections uncommon on the farm. Their success is augmented by the weak political voice of the rural poor who are denied potentially useful technical options.

Looking to the future, we anticipate that equally arbitrary framings will determine the regulatory fate of new genetic manipulation techniques, such as RNA interference, gene drives, or DNA cut-and-paste tools like CRISPR/cas9 (Bevan & Uauy 2013). In 2016, the US Department of Agriculture opted not to regulate a CRISPR/cas9 engineered mushroom because genes had been deleted rather than added. Regulatory systems that go beyond the assessment of risks and benefits to rely on distinctions between processes without scientific justification will find it more difficult to remain current and credible as science moves forward.

These qualifications from politics, culture, and social psychology extend but do not undermine insights based on the standard interest model: Farmer and corporate interests matter if recognized by the regulator and not counteracted by the mobilization of consumer doubts or social movement politics. Material interests of farmers, however, are limited as drivers of approval by the regulator because of well-known problems with information and mobilization, especially in low-income countries—Marx's "potatoes in a sack"—and persistent urban bias (Lipton 1977).

To this general pattern, we note one important qualification: An absence of official regulatory approval does not always block benefits from the diffusion of GE seeds. The material interests of farmers can drive diffusion of unauthorized seeds in underground networks and illegal markets (Gupta & Chandak 2005, Herring 2007, Herring & Kandlikar 2009, Ramaswami et al. 2012). Official data on uptake and benefits of biotech crops therefore systematically understate actual uptake and benefits. Though useful to farmers, the limitation of this dispersion of technical change for global agriculture is that only widely used older GE commodity crops exhibit this potential (e.g., Bt cotton and herbicide-tolerant soy). This path to uptake will shrink in importance if research and deployment continue to be blocked at the frontier. Looking forward, farmers in most developing countries will remain unable to use new varieties of GE food crops, or even the existing varieties, until consumers in rich countries change their minds about GMOs. Not for the first time in history, the tastes of the rich will drive welfare outcomes for the poor.

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