The Political Economy of Biotechnology

Die politische Ökonomie der Biotechnologie

David Zilberman
College of Natural Resources, Berkeley, CA, USA

Gregory Graff
College of Agricultural Sciences, Fort Collins, CO, USA

Gal Hochman
Rudgers University, New Brunswick, NJ, USA

Scott Kaplan
College of Natural Resources, Berkeley, CA, USA

Abstract

The introduction of GE to agriculture has encountered strong resistance, reflecting conflicting groups within and between countries. This has resulted in a regulatory environment that has limited the application of GE mostly to feed and fiber and practically restricted its application in food. While agricultural biotechnology has already provided significant benefits, much of its potential has not been reached. Regulation of agricultural biotechnology reflects conflicting interests and varying political power of different groups. The relatively supportive regulation of biotechnology in the U.S. reflects that it is an American technology, and supporting groups like the farm lobby, technology manufacturers, and U.S. consumers outweigh the objections of environmentalists and other opposition to the technology. In Europe, growing concern about environmental side-effects of agriculture, the fact that GE technology was imported, and the power of environmental groups has resulted in restrictive regulation. To a large extent, the fate of GE depends on the level of goodwill it generates among voters, and as long as a large segment of the population is apprehensive about its benefits, heavy restrictions about the technology that prevent it from reaching its potential will persist.

Key Words

bioeconomy; behavioural economics; genetic engineering; political economy; regulation

Zusammenfassung

Die Einführung von neuen Methoden in der Pflanzenzüchtung ist nicht unumstritten und spiegelt die Interessen gesellschaftlicher Gruppen auf nationaler wie auch international Ebene wider. Die unterschiedlichen Interessen haben dazu geführt, dass die neuen Methoden in der Pflanzenzüchtung stärker als die herkömmlichen reguliert werden und der Einsatz sich daher hauptsächlich auf Futter- und Faserpflanzen beschränkt. Obwohl der Einsatz der Biotechnologie in der Pflanzenzüchtung erhebliche Vorteile aufweist, ist das Potential bei weitem noch nicht ausgenutzt. Die Regulierung der Biotechnologie in der Landwirtschaft ist ein Ergebnis des politischen Einflusses von Interessensgruppen. Die wohlwollendere Regulierung in den USA erklärt sich daraus, dass es sich um eine amerikanische Technologie handelt, unterstützt von Landwirten, Pflanzenzüchtern und Verbrauchern, welches die Bedenken von Umweltschützern und anderen Gruppen, die die Technologie ablehnen, überwiegt. In Europa haben Bedenken über Umwelteffekte der modernen Landwirtschaft, die Tatsache, dass es sich um eine ausländische Technologie handelt und der Einfluss von Umweltschutzgruppen zu einer im Vergleich strengeren Regulierung der modernen Pflanzenzüchtung geführt mit einer im Endergebnis geringeren Anwendung der Technologie. Die Zukunft der Pflanzenzüchtung hängt davon ab, wie Wähler neue Methoden der Pflanzenzüchtung bewerten. Solange ein großer Teil der Bevölkerung den neuen Technologien kritisch gegenübersteht, ist zu erwarten, dass der Einsatz weiterhin stark eingeschränkt und das Potential nicht ausreichend genutzt wird.

Schlüsselwörter

Bioökonomie; Gentechnik; politische Ökonomie; Regulierung; Verhaltensökonomie

1 Introduction

The discovery of DNA in 1955 endowed humans with new capacities. It led to the development of new technologies that transformed and manipulated genes within organisms, including the Cohen-Boyer patent (BERA, 2009), which enabled genetic engineering (GE) in medicine, and agro-bacterium (AMARGER, 2002), which enabled GE in agriculture. The capacity for GE is growing, as the cost of sequencing the genome of different species is declining (THUDI et al., 2012) and new techniques like gene editing are being introduced (CAIN, 2013). While GE is applied regularly to medicine, and 40-45% of new drugs have some type of genetic modification (GWYNNE and HEEBNER, 2015), adoption of GE in agriculture remains limited.

GE technologies have been adopted on more than 180 million hectares in both developed (~50%) and developing (~50%) countries. It has been mostly adopted in 4 major crops – cotton, maize, rapeseed, and soybean, primarily in North and South America. But cotton has been adopted in India, China, and some African countries. GE has been adopted mostly in fiber and feed crops with few applications to food crops (e.g. papaya in Hawaii). There is significant scientific evidence that GE varieties increase yields, reduce commodity prices (corn by 10%, soybean by 20-40%, and cotton by 15-30%), reduce greenhouse gas (GHG) emissions, and save lives by reducing exposure to chemical pesticides (BARROWS, SEXTON and ZILBERMAN, 2014). There are also concerns about side effects of GE.[1] Yet, GE is practically banned in most of Europe and Africa. It has not been adopted in major food crops like wheat or rice and most fruits and vegetables, even though there are hundreds of traits available that can address problems of pests, nutritional deficiency in food, and abiotic environmental stresses like drought or extreme heat (BENNETT et al., 2013). This underutilization of GE in Europe and the rest of the world has been a result of regulatory regimes and constraints that have been the outcome of political economic systems. The main debate relating to the acceptance of GE technologies is between the U.S. and Europe, and according to PAARLBERG (2009), U.S. policy has more influence on the Western hemisphere while Europe has a greater influence on Africa. Therefore, we will emphasize political economic considerations in these countries.

The purpose of this paper is to develop a conceptual framework to interpret regulatory differences on GE between nations. We will rely on several bodies of economic literature and recent theory in our analysis. Theories, by nature, are fables that emphasize certain themes, and interpreting the complex story of GE technology requires weaving several theories together. Our analysis will primarily rely on basic concepts of political economy as well as behavioral economics, emphasizing dynamic processes, in particular the accumulation of good will towards GE, as well as the importance of path dependency.

The first section will provide an overview of the political economic literature, which will be followed by a section discussing its applications to GE. We will then identify key modeling features that are needed to gather a more realistic perspective on the economics of GE. In particular, we will include a section addressing heterogeneity within each of the groups that are part of the debate over GE. Following this section, we will analyze how behavioral economics can affect the understanding of the political economy of GE. This will be followed by a section identifying key elements of dynamic analysis that can provide a perspective on the evolution of policies affecting GE and the evolution of the technology. We will end with a conclusion.

2 An Overview of Political Economy

Classical economic models, like the Arrow-Debreu general equilibrium framework (ARROW and DEBREU, 1954), assume that technologies and preferences are given, and economic considerations determine the allocation of resources in production of goods, consumption patterns, and prices of goods. RUTTAN and HAYAMI (1984) argue that technology is the outcome of economic activity, research, and the direction of research, which is affected by market forces as well as institutional and regulatory constraints. Thus, different economic environments will result in a different direction of innovation. Their work provided the foundation for a large body of literature on innovation in agriculture (SUNDING and ZILBERMAN, 2001). ACEMOGLU and ROBINSON (2015) emphasize that economic choices are a result of institutions and policies that reflect political and economic power, and give rise to tech-

[1] For example, the herbicide Roundup Ready that is used on herbicide tolerant traits has been considered "probably carcinogenic" to humans. Roundup has been used for over 30 years, and these new findings are subject to controversy. Nevertheless, while there have been controversies about the health impact of GE, the vast majority of analysis of its impacts found it to be not less safe than traditional foods (PAARLBERG, 2009).

nologies and various measures of economic performance. Thus, understanding the regulation of GE technologies requires understanding the political structures and power that give rise to policy that affects GE technologies.

There are several bodies of work that explain how political systems affect regulatory decision-making, reflecting that decisions may be made through majority voting, by regulators apart from of the executive branch, and by elected representatives. DOWNS (1957) developed the median voter model for electoral political choices. It can be applied to selection among parties or candidates as well as propositions at the state and federal levels. POSNER (1974) introduced the theory of regulatory capture that addresses choices by regulators, arguing that regulators may be controlled by the industry they regulate. GROSSMAN and HELPMAN (2002) developed a nuanced theory of regulation, arguing that regulators take into account the weighted interest of various groups affected by their outcome. PELTZMAN (1998), and in particular BECKER (1983), develop a microeconomic theory that can be applied to elected representatives and regulators, both of whom take into account the considerations that affect their choices. These considerations affect their desire to be reelected, and thus their desire to satisfy their constituency, as well as the need to obtain funds to support their operation, which explains their tendency to give weight to various interest groups. RAUSSER, SWINNEN and ZUSMAN (2011) develop a more generalized political economic model that applies to different structures, where again political outcomes assign different weights to different interest groups, and applied this framework to U.S. agriculture. More recently, ANDERSON, RAUSSER and SWINNEN (2013) developed a political economic perspective to explain agricultural policy. Although not the focus of this paper, there is another body of literature that, instead of focusing on inefficiencies arising from differences in preferences among politicians and various groups, deals with incumbent governments' incentives to manipulate current policy as well as influence future elections and policy choices made by future governments (e.g., PERSSON and Svensson, 1989; PERSSON and TABELLINI, 2000). This paper builds on the former body of literature, and investigates how differences in preferences among politicians, producers, and consumers, result in regulatory systems that hinder the development of agricultural biotechnology.

There is an emerging body of literature on the political science perspectives of regulation of biotechnology (HERRING, 2008). GRAFF, HOCHMAN and ZILBERMAN (2014) provide a survey of the literature on political economy and a model expanding the median voter theorem to political economic choices. Their analysis applies to situations where a group of voters has to make a discrete choice with respect to a policy proposal. These voters may be members of the general public, in the case of a proposition at a state level in the U.S., or elected representatives in the case of a parliament. Propositions are designed with the hope that they obtain a majority vote, and in the case of individual voters, they will support a proposition (e.g. to ban GE foods) if their perceived gain from improved environmental benefits is greater than the additional utility lost because of higher food prices. An elected official will support a proposition to ban GE if the gain in terms of political and financial support obtained from groups that support the proposition outweighs the losses from groups that oppose it. Their analysis assumes that groups vary in their preferences, and different representatives assign different weights to different groups. Furthermore, the assessment of impact of different policy proposals and weights attached to them depends on information availability, which depends on the media. Their analysis also suggests that choices vary across countries, reflecting differences in institutional setups, political environments, and other factors. Our analysis will not present their formal model, but will rely on it and introduce dynamic and behavioral-economic considerations to develop new implications.

Policy-makers tend to make three major types of decisions regarding GE technologies. First is on the approval process, which can vary in its restrictions. At the extreme, they may ban field experiments with GE as well as production or consumption of GE. They may also set regulatory procedures for approval of GE that vary in detail, cost, and time requirements. For example, they may impose rather strict regulatory requirements every time a new trait is considered being introduced. Regulation may apply to large political entities (e.g. West Africa and the EU) or smaller ones (individual countries or states) (ZILBERMAN, 2006). A second set of regulation involves coexistence between GE and non-GE varieties, specifying liabilities related to gene flow or mandating distances between fields of conventional versus GE varieties (BECKMANN, SOREGAROLI, and WESSELER, 2006). Coexistence regulations are related to the GE residue threshold standard in non-GE crops. Stricter residue standards may lead to tighter coexistence regulations.

Finally, a third set of regulations relates to labeling of GE. One possibility is mandatory labeling, and the physical design of any label (i.e. it can be as alarming as cigarette labeling or more modest and informative, like nutritional information) is a significant consideration. Another possibility is to not require labeling, which may result in voluntary labeling. Each set of regulation may result in different outcomes in terms of availability, abundance, and price of GE products.

The political system manifests itself in decisions regarding approval, coexistence, and labeling, and political economic considerations affect proposals and voting behavior about each of these policy parameters. Groups that oppose GE technologies tend to favor the highest possible approval costs, and believe that any users of GE products should pay the price of its coexistence with traditional technologies. Thus, these opposing groups will support mandatory labeling of these products. On the other hand, supporters of GE prefer a regulatory system that has a quick and streamlined approval process. They also prefer that GE be the norm, and thus advocate for voluntary labeling of non-GE products. Finally, they would like to minimize the adjustments of GE producers to the concerns of non-GE producers over gene flow and other coexistence issues. In most of this paper, we use the term "regulation" generally, but there are cases where we look at attitudes towards political economic considerations that affect specific regulatory measures.

3 The Attitudes and Influence of Various Interest Groups on GE Regulation

Many strains of the political economic literature view the decisions about regulation of GE within a static framework, where different groups may vary in influence and perspective. In this section, we expand on the analysis in GRAFF, HOCHMAN and ZILBERMAN (2014) to identify some of the major parties in the debate over GE, their political weight, and credibility and influence on others. Credibility and influence are important, because several groups, including policymakers and consumers, may not be sufficiently informed about GE, and therefore rely on various sources of information to make their choices.

Table 1 identifies relevant groups contributing to the decision-making process relating to GE technologies. We identify the major considerations each group makes in determining their stance on GE, our assumptions about their political influence, their credibility as a source of information, as well as their attitude towards GE.

The table demonstrates the large number of groups that have concerns and impact on the regulation of GE. The welfare economic literature treats these groups as homogeneous entities and provides a first-order perspective on the response of these groups to GE, which will be addressed here. But while this literature mostly treats each group as homogeneous within countries, there may be differences between the interests of certain groups between countries. ZILBERMAN et al. (2013a) develop a detailed analysis of the perspective of each interest group and how they differ between the U.S. and EU.

We distinguish between two groups of policymakers: members of the executive branch that look more at aggregate measures of performance, and regional representatives that look at the well-being of their region (GRAFF, HOCHMAN and ZILBERMAN, 2014). In countries like China, the central government is very important, and one key issue is food security and lack of dependence on a foreign supplier. Thus, their support of GE would be much stronger if its development were undertaken domestically. Similar nationalist attitudes towards GE may exist in India (PRAY et al., 2011). In the case of the U.S., for example, the federal government may be interested in promoting GE technology because it is an export industry and can improve balance of trade. On the other hand, European governments may be less supportive of the technology as long as it results in reduced exports of pesticides.

As a whole, consumers will evaluate the impact of GE on food prices, but may be concerned about health or environmental risks. The price reduction associated with the introduction of GE is an indication of its benefit to consumers, and the 2010 NATIONAL RESEARCH COUNCIL (NRC) Report suggests that consumer surplus from the introduction of GE technologies ranges between 10-40% of the total social surplus. Thus, on the surface, consumers are likely to gain from the price effect of GE. However, agricultural commodities make up a small share of consumer expenditures, and even if they recognize it, consumers are a relatively dispersed group and may not have significant voice (GRAFF, HOCHMAN and ZILBERMAN, 2014). Consumers in Europe tend to distrust government regulations of new technologies and may give more weight to environmental constraints, and thus

they may be more open to criticism of GE (ZILBERMAN et al., 2013a).

Farmers may gain from GE because of reduced input costs as well as non-pecuniary externalities (reduced exposure to pesticides, reduced effort, etc.) as well as from the yield effect, but may suffer from the price effect, especially when there is widespread adoption and demand is inelastic. The NRC REPORT (2010) suggests that producer surplus increased by 5-25% because of GE, and QAIM (2009) suggests that profitability of farmers in India increased by 25% because of adoption of Bt cotton. However, as adoption levels and, as a result, the supply effect of GE increase, producer profitability may decline, which suggests that different groups of farmers may have different attitudes towards GE. For example, one of the objections of wheat farmers to GE wheat is the drastic price effect.

The biotechnology sector, large companies like Monsanto, Novartis, etc., and small start-up companies are the main champions of GE, and indeed the NRC REPORT (2010) suggests they gained between 20-70% of the surplus created by GE. At the same time, input suppliers (e.g. chemical companies) that provide products replaced by GE are the natural opposition to its introduction. Some of them may consider switching to genetic technologies in the long run, but may oppose their introduction during a transition period. GRAFF and ZILBERMAN (2007) showed that around 2000, sales of chemical inputs for agriculture declined by 10%, which was replaced by additional expenditures on GE seeds with pest-control traits. One contributing factor to the negative attitude of EU countries towards GE is that the large group of chemical input suppliers that were affected by GE are European, while most of the GE production sector is American.

The participants in the supply chain of food products may play an important role in shaping the future of GE products. Retailers are influenced by the impact of GE on their sales. If, for example, activists protest the sale of GE products in their local stores, then these retailers may discontinue the sale of GE products. The perspective of food distributors may be shaped by the extra cost imposed by GE and its regulation (e.g. labeling and coexistence regulation).

Table 1. Groups involved in the decision-making process over GE technologies

Interest Groups	Objectives	Credibility	Influence	Attitudes towards GE
Policymakers	Being elected/promoted; Fame and Fortune	High/ Low		Depends on constituents
Executive Branch	GNP; food security		High	
Parliamentary Representative	Well-being of their region		High	
Consumers	Low prices; Health; impact on environment	High	Low as group	Benefit from low prices; wary of risks
Farmers	High prices; good yield	Medium	High	May gain from reduced costs; may lose from reduced prices
Food intermediaries (retailers, wholesalers, and distributors)	Sales of food and crop; satisfied customers; reduce processing costs	High	High	Varies
Major biotech companies (e.g. Monsanto)	Profits from GM and other products; market power	Low	High	Positive
Startup biotech companies	Sell to big company	Low	Low	Positive
Competing input suppliers	Profits	Low	High	Negative
Academic institutions/ scientists	Obtain research support	High/Low	Medium	Varies
Environmental activist organizations	Be powerful; affect outcome	High/ Low	High	Negative

Source: authors

Academic institutions are interested in activities that will increase their budget as well as earnings from technology transfer, and to some extent they will tend to support introduction of GE to the extent that it will lead to an increased research budget. While there is evidence that GE increases various aspects of environmental quality (reduced agricultural footprint as well as GHG emissions), environmental groups tend to oppose GE. This may reflect both the uncertainty associated with these technologies as well as the conservative nature of environmental groups that leads them to oppose biology-manipulating technologies. While environmental groups are non-profit organizations, they need to obtain support to survive (ZILBERMAN et al., 2013a). Since many of their supporters have strong ecological preferences and believe in organic and eco-agriculture with minimal use of chemicals and modern inputs, the agenda of environmental groups will reflect these issues (ZILBERMAN et al., 2013a). Policy-makers as a group may implicitly be in favor of establishing regulation on GE because design of the regulation and implementation provides them with a source of power and influence.

This initial analysis of groups suggest that environmentalists as well as producers of inputs of products replaced by GE are likely to strongly oppose the technology while the main support may come from companies that produce GE technologies. Farmers may support GE under certain circumstances, while consumers and other groups may be more neutral and affected by specific information and circumstances.

It is important to acknowledge that attitudes towards and regulation of GE technologies may vary within countries depending on the ruling coalition, and may also vary among nations, reflecting differences in their economic situations (SWINNEN and VANDEMOORTELE, 2011). A coalition of producers, environmental groups, and consumers in a developed country may support stronger regulation of GE (giving higher weights to food prices and environmental quality), while a coalition of consumers and livestock farmers in a less developed country with stronger preferences for low prices may support less strict regulation of GE. Furthermore, SWINNEN and VANDEMOORTELE (2010) argue that the specifics of institutional structure and organizational constraints affect how political preferences come to bear, and thus the political outcomes of different organizations. The practical ban of GE in the EU is a large extent the outcome of its institutional structure as well as the preferences of different constituents.

4 The Importance of Heterogeneity

While some of the economic literature on attitudes towards GE recognizes heterogeneity within groups (LUSK, ROOSEN and BIEBERSTEIN, 2014), much of the literature treats individual groups as homogeneous. Yet, this intra-group diversity may have a significant impact on the debate over GE. Consumer differences in income and other preferences will lead to different opinions on these price effects. GRAFF, HOCHMAN and ZILBERMAN (2014) distinguish between price sensitive consumers, who value price as their primary criteria for purchase of food products, attribute-sensitive consumers, who prioritize product characteristics (e.g. “natural” food) in food purchases, and attribute price comparing consumers, who tend to balance between the two. Heterogeneity among consumers is manifested in HAMILTON, SUNDING and ZILBERMAN (2003), who show that while a majority of consumers are not willing to pay for pesticide-free food, 15% of consumers are willing to pay extra. Moreover, they found that 40% of Californians are willing to vote for banning pesticides, and some of the people willing to vote to ban pesticides are not willing to pay extra for pesticide-free food, suggesting that environmental concerns may be the cause for these voting decisions. ZILBERMAN et al. (2013b) show that when Proposition 37, which required mandatory labeling of GE products in California, was first brought to the table, 80% of consumers supported it. But once advertisers against the proposition suggested the costliness of labeling, it was defeated by 55% of the voters. The changing attitudes towards labeling of GE foods (HUFFMAN and MCCLUSKEY, 2014) suggest that many consumers do not have strong preferences for these products and are affected by new information. Furthermore, there is evidence that consumers are willing to pay extra for GE traits if they have desirable nutritional properties (MOSCHINI and LAPAN, 2006). The heterogeneity of consumers suggests that while there is a large majority that does not have a strong preference towards GE, there is a small minority that opposes it and may be active politically to push legislation against it.

Agricultural producers by nature are heterogeneous – they grow different crops depending on their region, and their attitudes towards GE may vary by crop or trait. Some of the organic growers in the U.S. oppose GE on ideological or practical grounds. They may support strong segregation policies because the price premium of organic farmers may suffer because of contamination by neighboring GE products. Organic

growers may also support strong labeling policies. Among conventional farmers, groups that benefit directly from a trait will be supportive of GE, while groups that do not benefit from existing traits but may lose from the price effect may actively or passively oppose it. Retailers are diverse as well. Some retailers (e.g. Whole Foods) may seek to build their brand by identifying with organic or environmentally friendly practices, and therefore will be at the forefront of efforts to regulate GE and introduce labeling. On the other hand, many food distributors may support reducing regulation in order to reduce their segregation and other operational costs. For example, while Whole Foods supported the GE labeling proposition in California, mainstream food distributors (e.g. the Grocery Manufacturer's Association) opposed it (ZILBERMAN et al., 2013b).

There is diversity of attitudes towards GE within the biotechnology industry and academic communities. While almost all biotechnology companies will strongly support policies that allow GE technologies to be introduced, larger companies are more likely to support stricter regulatory procedures than smaller companies. When the regulatory procedure is demanding, larger companies are more likely to have the resources to invest in regulatory efforts and introduce new technologies, and are less likely to face competition from small companies. Within universities, biotechnology researchers will strongly support the technology and an enabling regulatory environment. On the other hand, faculty members in some environmental disciplines may actually provide the intellectual foundation for opposition. University researchers provided the base for both eco-agriculture, which aims to minimize input use and promote biodiversity, as well as use of GE in agriculture. The difference between the two schools of thought represents the differences between organismal vs. molecular approaches to biology (BÖSCHEN et al., 2006; RAUSSER, ZILBERMAN and KAHN, forthcoming).[2] Similarly, the intensity of opposition or support for GE may vary within environmental groups (HALL and MORAN, 2006). Furthermore, the intensity of opposition to GE may vary among environmental groups. For some, like Greenpeace[3] and Food First, opposition to GE and support for stiff regulation against it is financially rewarding, while other groups may be less intense in their efforts.

The diversity within different groups that are part of the debate over GE leads to different attitudes and efforts in support of or in opposition to it. Even within groups that may significantly benefit overall from GE technologies or that are not affected, there may be subgroups that are vocal in their opposition and contribute to anti-GE campaigns through activism or financial contributions. The degree of support for or opposition to GE within groups may also vary across countries, reflecting country-level differences in agro-ecological and political situations.

5 Behavioral Economics

Much of the political economy literature is based on traditional microeconomic analysis using profit maximization and risk aversion behavior. However, there is a growing literature that emphasizes the importance of behavioral economics in explaining food choice patterns (WANSINK, JUST and PAYNE, 2009). Prospect theory laid the foundation for behavioral economic analysis. KAHNEMAN and TVERSKY (1979) emphasized three elements: loss aversion[4], where economic agents weigh losses on the margin more than they do gains, weighting of probabilities, which consists of assigning larger weights to lower probability events, and framing, where the outcome of choices depends on context.[5] These elements of behavioral economics may explain some of the attitudes that have been formed towards GE technologies. As we argue before, some of the objections for new GE crops came from manufacturers of inputs (e.g. pesticides) that were replaced by GE traits. Loss aversion may suggest that manufacturers of these inputs may be extremely fierce in their fights to protect their territory because of concern about losses or even bankruptcy due to GE. The intensity of the actions of the various agents involved

[2] Note, though, that E.O. WILSON (DOUGLAS, 2001; RAUSSER, ZILBERMAN and KAHN, forthcoming) recognized the importance of GE technology in the context of agriculture, but emphasized the need to combine ecological principles with biological technologies – a perspective very similar to Pam Ronald that looks to combine organic and GE agriculture.

[3] According to BONNY (2003), Greenpeace's anti-GE action was instrumental in bailing out and strengthening Greenpeace-France, which had been in serious financial straits and was experiencing a relative drop in its membership compared to other North European countries.

[4] Technically, the utility function is concave for gains and convex for losses.

[5] The "loss aversion" argument due to the concavity of the utility or political support functions has been central to much of the political economy of agricultural policy literature as well (SWINNEN and DE GORTER, 2002).

in the GE sector when it comes to regulation may reflect the extreme implications of certain regulatory decisions. Similarly, the tendency of consumers to overestimate small risks about GE may be due to the lack of evidence assuring them that the technology is completely safe. The establishment of a precautionary principle that aims to eliminate risk may originate from a similar tendency.

Finally, there are numerous studies that suggest framing matters. The media has introduced most of the public to GE technologies, and provided the vantage point (framing) that affected their perspective. CURTIS, MCCLUSKEY and SWINNEN (2008) argue that while the media may tend to emphasize negative news, differences in biases of the media as well as different levels of access between countries results in different attitudes of the consumers. HERRING (2008) suggests that consumers' negative attitudes towards GE technologies in agriculture originated because of the context in which they were presented by the opposition to GE – they were framed as hazardous technologies that were pursued by profit-seeking corporations and farmers without benefits to consumers. The term "Frankenfoods" provided a context that turned many consumers against GE technologies (MCCLUSKEY and SWINNEN, 2004). Furthermore, when decisions regarding GE were framed, there was no explicit recognition of the risk associated with *not* using GE and having to use alternative pest control strategies instead, which are also risky.

6 Dynamics and Learning

Much of the political economic literature is static, but public policy is evolving and dynamic considerations are quite important. Here, we will develop a framework to address some dynamic issues that affect the GE policy arena.

First, the regulatory process of a technology is dynamic and includes multiple stages (GRAFF, HOCHMAN and ZILBERMAN, 2009). These stages are: (i) the introduction and initial assessment of the technology and its impacts, (ii) a policy debate, where each sector aims to influence others, and (iii) the decision-making, which varies based on the institutional set-up. Some parties in the debate have a clear and obvious stake in the technology or a strong opinion about it (producers of GE technology, producers of alternative technologies, and environmental groups) and they will invest in influencing the belief and perception of policy-makers and groups that affect regulatory outcomes (e.g. the general public). Once technologies are introduced, their performance is monitored, and based on the results from monitoring, new decisions or policies may be needed over time. Agricultural GE technology consists of multiple traits and is evolving over time, and the regulations surrounding it are multidimensional, so the regulatory debates about its use are ongoing.

Second, the different parties that participate in the development of and debate over GE have dynamic perspectives. For example, Monsanto invests based on predictions about the future and results from the past. Other companies may oppose GE in the short run because they do not have access to intellectual property owned by Monsanto. But once these patents expire, these companies may change their perspective. Similarly, Greenpeace made an investment in establishing an anti-GE stance, and likely considered the long-run implications of this choice. Thus, understanding of political economy of GE requires understanding the dynamics of its evolution and different groups' perceptions.

Third, the attitudes of voters towards GE are evolving. Because voters make impacts both directly (when decisions are determined by a vote) or indirectly, since policy-makers need their support during elections, various parties aim to influence their perspective on the technology. Individual voters may establish an attitude towards GE, but because of the inherent uncertainty about its impact, consumers may adjust their opinion based on the technology's performance as well as new information that becomes available. One way to analyze the evolution of these attitudes is to apply the concept of goodwill towards a brand introduced through marketing (BATTRA, LEHMANN and SINGH, 1993; HEIMAN et al., 2001). Goodwill can be viewed as a stock variable that evolves over time. Each individual may have his or her own goodwill indicator at any moment that reflects his or her assessment of the benefit and risk the technology imposes on him or herself as well as society. One can also measure goodwill in aggregate across all members of society (HOCHMAN, GRAFF and ZILBERMAN, 2012). The goodwill one feels towards a technology is updated over time based on evidence about its merits as well as any negative effects associated with the technology, and the decision an individual makes in voting about a technology's fate (i.e. whether to ban it, label it, etc.) will depend on their level of goodwill, among other considerations. Different parties interested in affecting the GE policy environment may engage in activities that affect individual goodwill, including

studies that show the gain from these technologies and publication of results that document some of its deficiencies. For example, studies showing that GE varieties may cause cancer were publicized prior to the vote on the proposition to require labeling of GE food products in California (ZILBERMAN et al., 2013b). One reason that Greenpeace opposed the introduction of Golden Rice is that its success may generate more goodwill towards GE technology, which will lead to more favorable attitudes towards and regulation of it (HERRING, 2008).

Fourth, the evolution of GE is path dependent – namely, history matters. In particular, since outcomes are subject to randomness, once they occur they provide initial conditions for future choices and action. Goodwill of consumers towards GE is affected by past performance of the technology and the past narrative (HOCHMAN, GRAFF and ZILBERMAN, 2012). Dedication of activists to their anti-GE agenda is affected by their past success. Company choices about what traits to develop and which markets to target are affected by future projections based on the past.

SWINNEN et al. (2015) develop a theory where hysteresis in regulatory differences has a long lasting effect. Specifically, they emphasize the importance of path dependency on the evolution of regulation. Drastic changes in preferences in one country that occur at a given moment in time may lead to strict regulation, and consumers and producers in that country will adjust their behavior and attitudes to these changes, and will oppose change in this regulation in the future even when the crisis disappears. Their argument can be used to explain the differences in regulation of GE between the U.S. and Europe. They note VOGEL'S (2003) observation that until the 1980s, the U.S. environmental policies were stricter than Europe, but post 1980s, European policies had a strong precautionary element. Furthermore, the attitudes towards GE were not different in the U.S. and Europe before the 1990s, but diverged after this period. This may have been caused by food scares in Europe in the second half of the 1990s (due to Mad Cow and Food and Mouth Diseases), which may have triggered higher consumer demand for product quality and resulted in stricter regulation of food and GE. Once these stricter regulations were introduced, the public and industry in Europe adjusted to them, leading to a permanent shift to more critical attitudes towards GE.

The insightful analysis in SWINNEN et al. (2015) underscores the importance of path dependence in attitudes towards and regulation of GE. But, there are other past events that seem to have significantly affected the evolution of the technology and attitudes towards it. The first GE traits considered in agriculture were ice-minus, which was a trait that allowed strawberries to survive low temperatures, and Flavr Savr tomatoes, a product-quality trait that aimed to increase the shelf life of tomatoes (KRAMER and REDENBAUGH, 1994). Flavr Savr was available in both the U.S. and Europe with little objection, but failed for commercial reasons (MARRA, PARDEY and ALSTON, 2002). Initially, there was optimism about using GE for natural nitrogen fixation, but it has not panned out. It seems that if the first successful applications were nitrogen fixation or extending shelf life, it would have been more difficult to negatively frame the technology as mostly benefitting industry with no benefits to consumers. The first traits successfully introduced commercially were insect-resistant and herbicide-tolerant traits, which did not seem relevant to consumers. At the same time, science fiction films and other works hyperbolized the risk of genetic engineering,[6] and made consumers apprehensive about the technology. This apprehensiveness was especially notable in Europe.

GE technologies were introduced by an American corporation (Monsanto) that was perceived as an aggressive "biotech bully boy," and its campaign to promote the technology combined with activist pushback backfired, reducing consumer goodwill towards the technology (LYNCH and VOGEL, 2001). The introduction of pest-controlling traits reduced the profitability of chemical companies, many of which were European (GRAFF, HOCHMAN and ZILBERMAN, 2014), and loss aversion may have motivated them to support actions to regulate the technology (at least until they are able to catch up). GE was also introduced during a period when Europeans were concerned about food safety, and many lost their trust in government food standards as a result of the appearance of Mad Cow Disease and concern about Hoof and Mouth Disease (GRAFF, HOCHMAN and ZILBERMAN, 2014; FINUCANE, 2002). Some of the activists have relied on anti-American and anti-globalization sentiments in Europe (LYNCH and VOGEL, 2001), especially during the early 1990s when the U.S. refused to join the Kyoto Protocol. This background reduced consumer goodwill towards the technology and enabled EU regulatory action, including labeling and other restrictions that led to a practical ban on using the technology in agriculture there after 1999 (LYNCH and VOGEL, 2001; GRAFF, HOCHMAN and ZILBERMAN, 2014).

[6] Attack of the Killer Tomatoes (1978)

The success of activists in spreading the use of the technology was not limited to Europe. Monsanto attempted to introduce GE potatoes in the 1990s, but McDonalds, who was the largest buyer of potatoes, decided not to purchase them in part because of pressure from activists who aimed to picket if they did, leading Monsanto to drop this technology (TOEVS et al., 2011). The restriction of GE in Europe as well as the failure of GE potatoes in the U.S. enhanced apprehension towards the technology, which was associated with the contraction of innovative efforts in GE that occurred around this period (GRAFF, ZILBERMAN and BENNETT, 2009).

Since 2000, most of the commercial development of traits has been concentrated on crops for feed and fiber and not for food. The Europeans tolerate importing GE feed and cotton, but restrict its introduction to food crops, and China and India have not introduced GE rice, including Golden Rice, thus far. PAARLBERG (2001) sees this as a political economic equilibrium. A key element of the current arrangement is the strict regulation on GE technologies in Europe and the Cartagena Protocol for biosafety that imposes very strict restrictions on the introduction of new GE varieties, which requires significant investment in biosafety mechanisms and strict compliance standards (PAARLBERG, 2001).

The burden of the current restrictive environment on the use of GE is felt mostly by developing countries, especially in Africa, that could benefit immensely from the introduction of GE varieties for food crops, including rice, bananas, wheat, and corn. ZILBERMAN, KAPLAN and WESSELER (2015 forthcoming) estimate that the expected annual net welfare loss from delaying the introduction of GE varieties in wheat, rice, and corn (in the countries that do not allow it) is between $50-97 billion, and banning these technologies outright will result in a discounted welfare loss between $300 billion and $1.22 trillion. Most of the losses will be incurred by consumers because of higher prices, and banning these technologies will result in the expansion of agricultural acreage and an increase in GHG emissions as a result.

7 Conclusion

Agricultural biotechnology was introduced to apply modern tools of molecular biology to enhance agricultural productivity and reduce its environmental footprint. But unlike medicine, the introduction of GE to agriculture has encountered strong resistance that reflects conflicting groups within and between countries. This has resulted in a regulatory environment that has limited the application of GE mostly to feed and fiber and practically restricted its application in food. While agricultural biotechnology has already provided significant benefits, much of its potential has not been reached.

Our analysis of the evolution of the political economic environment surrounding agricultural biotechnology recognizes the impact of heterogeneity between groups, the dynamic forces that shape goodwill towards the industry, behavioral patterns deviating from standard profit maximization that reflect suspicions about the technology, and the dynamic processes of learning and interaction between groups. To a large extent, the fate of GE depends on the level of goodwill it generates among voters, and as long as a large segment of the population is apprehensive about its benefits, heavy restrictions about the technology that prevent it from reaching its potential will persist.

Finally, our analysis emphasizes the importance of path dependency – namely that actions and random shocks occurring in the past have resulted in policy, institutions, and technological innovation that are shaping the future. This analysis suggests that the future of GE is quite open. One can foresee scenarios where excessive regulatory pressure persists, which may lead to development of institutions and technologies where GE becomes marginalized. Alternative scenarios where the pressure of climate change and population growth combined with technological breakthroughs and appreciation of the past benefits of GE may lead to a more enabling regulatory environment that will allow society to take advantage of the potential of GE. While thus far much of the development of GE technologies has occurred in the U.S., significant development and deployment of GE technologies in developing countries like China and India may play an important role in moving the technology forward.

References

ACEMOGLU, D., and J. ROBINSON (2015): The rise and decline of general laws of capitalism. In: Journal of Economic Perspectives 29 (1): 3-28.

AMARGER, N. (2002): Genetically modified bacteria in agriculture. In: Biochemie 84 (11): 1061-1072.

ANDERSON, K., G. RAUSSER and J. SWINNEN (2013): Political economy of public policies: insights from distortions to agricultural and food markets. In: Journal of Economic Literature 51 (2): 423-477.

ARROW, K.J. and G. DEBREU (1954): Existence of an equilibrium for a competitive economy. In: Econometrica: Journal of the Econometric Society 22 (3): 265-290.

BARROWS, G., S. SEXTON and D. ZILBERMAN (2014): Agricultural biotechnology: The promise and prospects of genetically modified crops. In: The Journal of Economic Perspectives 28 (1): 99-119.

BATRA, R., D.R. LEHMANN and D. SINGH (1993): The brand personality component of brand goodwill: some antecedents and consequences. In: Aaker, D.A., A.L. Biel (eds.): Brand equity and advertising. Chapter 6. Psychology Press, New York: 83-96.

BECKER, G.S. (1983): A theory of competition among pressure groups for political influence. In: The Quarterly Journal of Economics 98 (3): 371-400.

BECKMANN, V., C. SOREGAROLI and J. WESSELER (2006): Coexistence rules and regulations in the European Union. In: American Journal of Agricultural Economics 88 (5): 1193-1199.

BENNETT, A.B., C. CHI-HAM, G. BARROWS, S. SEXTON and D. ZILBERMAN (2013): Agricultural biotechnology: economics, environment, ethics, and the future. In: Annual Review of Environment and Resources 38: 249-279.

BERA, R.K. (2009): The story of the Cohen-Boyer patents. In: Current science 96 (6): 760-763.

BONNY, S. (2003): Why are most Europeans opposed to GMOs?: Factors explaining rejection in France and Europe. In: Electronic Journal of Biotechnology 6 (1): 7-8.

BÖSCHEN, S., K. KASTENHOFER, L. MARSCHALL, I. RUST, J. SOENTGEN and P. WEHLING (2006): Scientific cultures of non-knowledge in the controversy over genetically modified organisms (GMO): the cases of molecular biology and ecology. In: GAIA-Ecological Perspectives for Science and Society 15 (4): 294-301.

CAIN, C. (2013): CRISPR genome editing. In: SciBX: Science-Business eXchange 6 (4).

CURTIS, K.R., J.J. MCCLUSKEY and J. FM SWINNEN (2008): Differences in global risk perceptions of biotechnology and the political economy of the media. In: International Journal of Global Environmental Issues 8 (1-2): 77-89.

DOUGLAS, E. (February 16, 2001): Darwin's natural heir. In: The Guardian. Accessed: http://www.theguardian.com/science/2001/feb/17/books.guardianreview57.

DOWNS, A. (1957): An economic theory of political action in a democracy. In: The journal of political economy 65 (2): 135-150.

FINUCANE, M.L. (2002): Mad cows, mad corn and mad communities: the role of socio-cultural factors in the perceived risk of genetically-modified food. In: Proceedings of the Nutrition Society 61 (01): 31-37.

GRAFF, G.D. and D. ZILBERMAN (2007): The political economy of intellectual property: Reexamining European polity on plant biotechnology. Agricultural biotechnology and intellectual property: Seed on change. CAB International, Cambridge, M: 244-267.

GRAFF, G., G. HOCHMAN and D. ZILBERMAN (2014): The Political Economy of Regulation of Biotechnology in Agriculture. In: Herring, R.J. (ed.): The Oxford Handbook of Food, Politics, and Society. Oxford University Press, Oxford.

– (2009): The Political Economy of Agricultural Biotechnology Policies. In: AgBioForum 12 (1): 34-46.

GRAFF, G.D., D. ZILBERMAN and A.B. BENNETT (2009): The contraction of agbiotech product quality innovation. In: Nature biotechnology 27 (8): 702-704.

GROSSMAN, G.M. and E. HELPMAN (2002): Special interest politics. MIT press, Cambridge, MA.

GWYNNE, P. and G. HEEBNER (2015): Drug Discovery and Biotechnology Trends: Recent Developments in Drug Discovery: Improvements in Efficiency. In: Science 7 (February).

HALL, C. and D. MORAN (2006): Investigating GM risk perceptions: a survey of anti-GM and environmental campaign group members. In: Journal of Rural Studies 22 (1): 29-37.

HAMILTON, S.F., D.L. SUNDING and D. ZILBERMAN (2003): Public goods and the value of product quality regulations: the case of food safety. In: Journal of Public Economics 87 (3): 799-817.

HEIMAN, A., B. MCWILLIAMS, Z. SHEN and D. ZILBERMAN (2001): Learning and forgetting: Modeling optimal product sampling over time. In: Management Science 47 (4): 532-546.

HERRING, R.J. (2008): Opposition to transgenic technologies: ideology, interests and collective action frames. In: Nature Reviews Genetics 9 (6): 458-463.

HOCHMAN, G., G. GRAFF and D. ZILBERMAN (2012): The Political Economy of Controversial Technologies. In: 2012 Annual Meeting, August 12-14, 2012, Seattle, Washington, no. 124953. Agricultural and Applied Economics Association, Milwaukee, WI.

HUFFMAN, W.E. and J.J. MCCLUSKEY (2014): Labeling of genetically modified foods. In: Handbook on Agriculture, Biotechnology and Development 467, Chapter 30.

KAHNEMAN, D. and A. TVERSKY (1979): Prospect theory: An analysis of decision under risk. In: Econometrica: Journal of the Econometric Society 74 (2): 263-291.

KRAMER, M.G. and K. REDENBAUGH (1994): Commercialization of a tomato with an antisense polygalacturonase gene: The FLAVR SAVR™ tomato story. In: Euphytica 79 (3): 293-297.

LUSK, J.L., J. ROOSEN and A. BIEBERSTEIN (2014): Consumer Acceptance of New Food Technologies: Causes and Roots of Controversies. In: Annual Review Resource Economics 6 (1): 381-405.

LYNCH, D. and D. VOGEL (2001): The regulation of GMOs in Europe and the United States: A case-study of contemporary European regulatory politics. In: Council on Foreign Relations. Council on Foreign Relations Press, New York, NY.

MARRA, M.C., P.G. PARDEY and J.M. ALSTON (2002): The payoffs to agricultural biotechnology: an assessment of the evidence. Environment and Production Technology Division, International Food Policy Research Institute, Washington, D.C.

MCCLUSKEY, J.J. and J.F.M. SWINNEN (2004): Political economy of the media and consumer perceptions of biotechnology. In: American Journal of Agricultural Economics 86 (5): 1230-1237.

MOSCHINI, G.C. and H. LAPAN (2006): Labeling regulations and segregation of first-and second-generation GM products: Innovation incentives and welfare effects. In:

Regulating agricultural biotechnology: Economics and policy. Springer, New York, NY, USA: 263-281.

NRC (National Research Council) (2010): Impact of genetically engineered crops on farm sustainability in the United States. Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability. The National Academies Press, Washington, D.C.

PAARLBERG, R.L. (2001): The politics of precaution: Genetically modified crops in developing countries. International Food Policy Research Institute, Washington, DC?. The Johns Hopkins University Press, Baltimore, MD.

PAARLBERG, R.L. (2009): Starved for Science: How biotechnology is being kept out of Africa. Harvard University Press, Cambridge, MA.

PELTZMAN, S. (1998): Political participation and government regulation. The University of Chicago Press, Chicago, IL.

PERSSON, T. and L. EO SVENSSON (1989): Why a stubborn conservative would run a deficit: Policy with time-inconsistent preferences. In: The Quarterly Journal of Economics 104 (2): 325-345.

PERSSON, T. and G. TABELLINI (2000): Political economics: explaining public policy. MIT Press, Cambridge, MA.

POSNER, R.A. (1974): Theories of Economic Regulation. In: Bell Journal of Economics and Management Science 5 (2): 335.

PRAY, C.E., L. NAGARAJAN, J. HUANG, R. HU and B. RAMASWAMI (2011): The Impact of Bt Cotton and the Potential Impacts of Biotechnology on Other Crops in China and India. In: Carter, C.A., G.C. Moschini and I.M. Sheldon (eds.): Genetically Modified Food and Global Welfare. Chapter 4. Vol. 10. Emerald Grop Publishing Limited, Bingley, UK: 83-114.

QAIM, M. (2009): The economics of genetically modified crops. In: Annual Review of Resource Economics 1 (1): 665-694.

RAUSSER, G.C., J. SWINNEN and P. ZUSMAN (2011): Political power and economic policy: Theory, analysis, and empirical applications. Cambridge University Press, New York, NY.

RAUSSER, G., D. ZILBERMAN and G. KAHN (forthcoming): An alternative paradigm for food production, distribution, and consumption: a non-economist's perspective. In: Annual Review of Resource Economics.

RUTTAN, V.W. and Y. HAYAMI (1984): Toward a theory of induced institutional innovation. In: The Journal of Development Studies 20 (4): 203-223.

SUNDING, D. and D. ZILBERMAN (2001): The agricultural innovation process: research and technology adoption in a changing agricultural sector. Handbook of agricultural economics 1: 207-261.

DE GORTER, H. and J. SWINNEN (2002): Political economy of agricultural policy. Handbook of agricultural economics 2: 1893-1943.

SWINNEN, J. and T. VANDEMOORTELE (2010): Policy gridlock or future change? The political economy dynamics of EU biotechnology regulation. In: AgBioForum 13 (4): 291-296.

– (2011): Trade and the political economy of food standards. In: Journal of Agricultural Economics 62 (2): 259-280.

SWINNEN, J., K. DECONINCK, T. VANDEMOORTELE and A. VANDEPLAS (2015): Butterflies and political economy dynamics in a standard setting. In: Quality Standards, Value Chains, and International Development: Economic and Political Theory. Chapter 8. Cambridge University Press, New York, NY.

THUDI, M., Y. LI, S.A. JACKSON, G.D. MAY and R.K. VARSHNEY (2012): Current state-of-art of sequencing technologies for plant genomics research. In: Briefings in Functional Genomics 11 (1): 3-11.

TOEVS, E.A., J.F. GUENTHNER, A.J. JOHNSON, C.S. MC INTOSH and M.K. THORNTON (2011): An industry perspective of all-native and transgenic potatoes. In: AgBioForum 14 (1): 14-19. Available on: http://www.agbioforum.org.

VOGEL, D. (2003): The hare and the tortoise revisited: The new politics of consumer and environmental regulation in Europe. In: British Journal of Political Science 33 (4): 557-580.

WANSINK, B., D. JUST and C.R. PAYNE (2009): Mindless eating and healthy heuristics for the irrational. In: American Economic Review 99 (2): 165-169.

WILSON, EO., interviewed by Jorge Salazar (2 December 2011): E.O. Wilson on the Future of Biology. Earthsky. URL: http://earthsky.org/human-world/e-o-wilson-on-the-future-of-biology.

ZILBERMAN, D. (2006): The Economics of Biotechnology Regulation. In: Just, R., J. Alston and D. Zilberman (eds.): Regulating Agricultural Biotechnology: Economics and Policy. Springer, New York: 243-261.

ZILBERMAN, D., S. KAPLAN, E. KIM, G. HOCHMAN and G. GRAFF (2013a): Continents divided: Understanding differences between Europe and North America in acceptance of GM crops. In: GM crops & food 4 (3): 202-208.

ZILBERMAN, D., S. KAPLAN, E. KIM and G. WATERFIELD (2013b): Lessons from the California GM labeling proposition on the state of crop biotechnology. In: Smyth, S., P. Phillips and D. Castle (eds.): Handbook on Agriculture, Biotechnology, and Development. Chapter 34. Edward Elgar Publishing Limited, Cheltenham, UK.

ZILBERMAN, D., S. KAPLAN and J. WESSELER (forthcoming): The loss from underutilizing GM technologies. In: Agbioforum (forthcoming).

Contact author:
PROF. DR. DAVID ZILBERMAN
207 Gianni Hall, Dept. of Agricultural and Resource Economics, College of Natural Resources
Berkeley, CA 94720, USA
e-mail: zilber11@berkeley.edu