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Source: BioScience, 55(3) : 265-272

Published By: American Institute of Biological Sciences

URL: https://doi.org/10.1641/0006-3568(2005)055[0265:BIAGWT]2.0.CO;2

Biotechnology in a Globalizing World: The Coevolution of Technology and Social Institutions

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Major debates about the safety of biotechnology for human health, the environment, and socioeconomic systems have marked the introduction of genetically modified foods into the global economy. Since their advent in the early 1970s, techniques for gene splicing and recombination have provided the basis for biotechnology's revolutionary promise to transform economic systems in unprecedented ways. The fact that this transformation is done by modifying living organisms has inspired awe as well as fear. Biotechnology is closely linked with globalization, and advances have influenced its diffusion and the corresponding social responses in mobility (of people, goods, and ideas), connectivity (through communications technologies), and economic interdependence (through global value chains and trading networks) (Narula 2003).

Much of the material on this debate has appeared mostly in the popular literature available on the Internet. The picture that emerges from a review of recent books on the subject is one of complex interactions between technological innovation and institutional change, interactions that defy deterministic interpretations. Advances in biotechnology continuously lead to adjustments in social institutions (defined here as the perceptions, practices, and rules that govern the relations and interactions between individuals and groups). In turn, social institutions influence the pace and direction of technological innovation. This article explores these interactions in fields such as environmental and safety regulation, ethics, socioeconomic considerations, intellectual property rights, international trade, and agriculture in developing countries.

Technology and institutions

The coevolutionary interactions between technological innovation and institutional change are emerging as key aspects of public policy (Fagerberg et al. 2005). Emerging studies on the introduction of biotechnology in the global economy bear this out. *Engineering Trouble* (Shurman et al. 2003) provides a clear map of the contours of the controversy, identifying its institutional and political features. Economic history has already provided an outline of the interactions between culture and technological change (Randall 1991). A more robust picture of these interactions is emerging from contemporary studies that adopt coevolutionary approaches (Mokyr 2002). *The Regulation of Agricultural Biotechnology* (Evenson and Santaniello 2004) shows the evolution of regulatory measures associated with the biotechnology of farming.

An excellent example of such an approach is *Trading the Genome* (Parry 2004), which investigates how the commercialization of bioinformation has coevolved with a variety of institutional innovations through history. The book not only brings rigorous analysis to this area of analysis, it serves as a rich source of information and new directions for research. *Genes, Trade, and Regulation* (Bernauer 2003) offers an excellent account of how controversies surrounding trade in biotechnology are polarizing major trading blocs in a more recent development. For those interested in a scientific approach, *Mendel in the Kitchen* (Federoff and Brown 2004) is an excellent offering. Indeed, biotechnology is not just about food production; its generic character has applicability in a wide range of agricultural, pharmaceutical, and environmental sectors (Scranton and Schrepfer 2003). Its march into other fields of human endeavor appears to be unstoppable (Winston 2002).

These studies, however, address issues that have broad cultural contexts often ignored by academics and policymakers. *French Beans and Food Scares* (Freidberg 2004) provides a rich analysis of the linkages between globalization and concerns about food safety. *Food Safety and the WTO* (Echols 2001) provides similar analyses with a specific focus on international trade rules regarding food. Both books provide indispensable foundational material for understanding the cultural underpinning of international trade in food in general (Atkins and Bowler 2001). These books demand that we view food not just as a commodity, but as a cultural state-

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ment that explains why debates surrounding food safety have been difficult to resolve by the mere invocation of scientific evidence. It is through these analytical frameworks that scholarship can break from classical approaches, which tend to frame the relationships between technology and society in deterministic terms (Smith and Marx 1994).

The picture that emerges from the literature on the introduction of biotechnology into the global economy shows that the interactions between technological change and institutional innovation do not exhibit any linear relationships; rather, they appear to be part of evolving market systems that influence—and in turn are influenced by—technological innovation and institutional adaptations. Social science therefore complements technical knowledge in the design of institutions, as articulately argued in *Social Science Knowledge and Economic Development* (Ruttan 2003).

These interactions between technology and culture are reflected in the politics of food safety, as so clearly documented in *Safe Food* (Nestle 2003) and *Food Politics* (Nestle 2002). *First Fruit* (Martineau 2001) provides an interesting case study of the early attempts to ensure that biotechnology products were adequately regulated; *Lords of the Harvest* (Charles 2001) provides a broader account of corporate efforts to gain legitimacy in global public opinion.

But sections of the public have remained concerned that existing regulatory institutions have not changed enough to ensure the safety of genetically modified foods. These concerns are reflected in graphic titles such as *Eating in the Dark* (Hart 2002) and *Killer Foods* (Fox 2004) (see also Lambrecht 2001, Cook CD 2004). Political alliances between social movements and the media amplify these concerns (Priest 2001). Fearmongering seems to be a hallmark of many of such works (Pringle 2003). However, the technological exuberance evident in works such as *BioEvolution* (Fumento 2003) counterbalances these concerns.

Technological uncertainty seems to be a dominant feature of the emergence and diffusion of biotechnology. Under the circumstances, we have fewer tools for analysis and must turn to systems thinking for heuristics. Biological analogies are not only used to analyze the unfolding of technological systems, as shown in *Evolutionary Innovations* (McKelvey 2000) and *The Economic Dynamics of Modern Biotechnology* (McKelvey et al. 2004). They are also informing the design of new technological systems, as in the case of biologically inspired computing (Forbes 2004). This worldview may be at odds with traditional approaches that emphasize predictability and seek minor opportunities to uphold deterministic models. Although biocomputing may not always be the best way to model reality, most of the evidence available seems to point to a more complex and dynamic world than that represented by traditional models (de la Mothe and Niosi 2000).

The introduction of new technologies can destabilize global markets that had reached a temporary state of equilibrium. The ensuing process of mutual adjustment involves not only changes in the economic institutions but also modifications in the new technological systems. Popular debates, legal wrangles, new research programs, safety protocols, and many features of the technological systems themselves are part of this process of coevolution. The main challenge is how to accommodate novelty in a system whose stability is defined by the existing technologies and institutions.

Emergence of biotechnology

Initial efforts to bring the products of agricultural biotechnology to the market have been met with considerable opposition, especially in Europe. Opponents often view new agricultural production processes as threats to existing agro-industrial structures and their associated value systems. In addition, groups opposing transgenic products draw on environmental and human health concerns when challenging regulatory and marketing decisions. In other words, uncertainty now serves a political function.

Molecular biology and related fields have developed a wide range of tools, products, and services that will have a remarkable impact on agricultural production in the coming years. Developments in other fields, such as information technology, to form new technological confluences complement these advances. Related institutional arrangements that seek to use knowledge and technologies to promote stronger international competitiveness through national champions have also emerged, as illustrated by examples in *Trade Warriors* (Busch 2001).

These advances are taking place in an era of globalization and market liberalization that promotes greater competition among nations and regions around the world (Stiglitz 2002). The ability of any one country to compete effectively in this emerging global market is largely dependent on its technological capabilities. As a result, one cannot easily separate debates on the commercialization of biotechnology products from the larger context of competition among nations and among multinational corporations in the global market. Within this context, current debates about biotechnology's impacts on economic structures, human health, and the environment coexist within the broader framework of market liberalization and its implications for existing patterns of agricultural production in different parts of the world. As a result, debates about biotechnology serve as a lightning rod for more fundamental concerns among nations regarding the prospects and risks of market liberalization.

The first major commercial applications of biotechnology have focused on improving existing products through the application of new agronomic traits. As a result, much of the technology is used in products of relevance to industrialized or temperate regions. This is partly due to the accumulation of knowledge in areas with previous investments in biotechnological capabilities and supportive institutions. *Seeds of Contention* (Pinstrup-Andersen and Schiøler 2000) shows how developing countries, which need biotechnology the most, are the least involved in its development and, therefore, the most vulnerable to the impacts of debates originating from the industrialized countries. Their institutional structures have yet to coevolve with biotechnology.

Coevolutionary adjustments

Interactions between technological change and institutional adjustment manifest themselves in a variety of biotechnological fields, including ethics, safety and environmental regulation, socioeconomic considerations, and intellectual property protection and international trade.

Ethical considerations. Ethical issues invoked in discussions regarding biotechnology may be part of a broader rethinking of the moral landscape, as mapped out in *The New Ethics* (Allen 2004). They are not mere rhetorical devices crafted to win or lose arguments (Cook G 2004). *Engineering the Farm* (Bailey and Lappé) shows that the issues at hand are closely tied to fundamental differences in worldview among major regions of the world. Ethical foundations are a key source of epistemological guidance in public discourse and policy. This consideration confers on ethics both conceptual and practical roles in guiding bioscience research and business (Eaton 2004).

For purposes of public policy, ethical considerations help the international community map trends in the debate on biotechnology and establish the moral parameters relating to specific applications (Ruse and Castle 2003). There are those who seek universal principles in the face of a technology whose impacts can be assessed only in specific conditions. For example, they question whether it is morally licit to own life or parts thereof (Resnik 2004). Others take a more utilitarian view of biotechnology's role in society, especially in developing countries (Nuffield 1999, 2004). The separation between intrinsic and extrinsic values has become a major moral dilemma that seems to find resolution through practical needs rather than theoretical gymnastics (Comstock 2000).

Ethical considerations—whether implicit or explicit—have had a major impact on institutional design for biotechnology regulation. The determination of whether it is acceptable to transform living organisms is a deep moral issue that has not only guided policymakers but drawn the constant attention of custodians of moral traditions. Current debates over stem cell research illustrate this point (Parson 2004). One of the most important outcomes of this moral debate has been the shaping of public involvement in decisionmaking and the emergence of fields such as corporate social responsibility.

Safety and environmental regulation. The US regulatory system for agricultural biotechnology is based on existing food safety and environmental regulations at three government agencies. It uses scientific review at various stages in the development process to determine final product approval. Because it is the government's policy that the risks to human health and the environment posed by new biotechnologies are essentially the same as those posed by similar products derived from conventional breeding techniques, no new legislation has been passed specifically to mandate regulation of biotechnology products. This is largely because existing statutory authorities are considered adequate. Federal regulatory oversight focuses on the characteristics and scientifically determined risks of the biotechnology product rather than the process by which it is created. A biotechnology product's use determines the agencies' jurisdiction over it.

The concept of the "substantial equivalent" is the basis of the regulatory approach outlined above. Critics say it embodies a preconceived commitment to avoid properly examining crops and foods modified through biotechnology. Substantial equivalence, however, is a conclusion, not a preconception, and it is reached only after crops or foods improved through biotechnology have been scrutinized against specific criteria (McHughen 2000). Before a conclusion on equivalence is reached, these crops and foods must be shown not to differ from their conventional counterparts in terms of any significant parameters involving molecular composition, potential allergenicity or toxicity, and nutritional or dietary impact.

Once questions relating to these characteristics are addressed, crops and foods modified through biotechnology can be considered substantially equivalent to their conventional counterparts, and thus do not require additional or special regulatory oversight. If material differences in composition or quality are revealed as a result of this scrutiny, the nature of the differences provides an indicator for regulatory authorities as to how they should proceed to ensure appropriate handling.

A second overarching principle of regulatory review guiding government policy is the streamlining of the regulatory burden to provide biotechnology firms, as much as possible, with a predictable regulatory environment that continues to encourage and foster scientific technological innovation. For those biotechnology products requiring review because of the risks they pose, regulatory review aims to minimize the regulatory burden while assuring the protection of public health and welfare.

The United States has adopted an incremental approach to the regulation of biotechnology, responding to new scientific evidence and adopting new laws and regulations. Institutions such as the National Academies that advise the government on matters related to science, technology, engineering, and medicine generate much of this evidence. Concern over the impact of transgenic corn on monarch butterflies, for example, inspired a study by the National Academies that recommended adjustments in government regulation (NRC 2000, 2002). The StarLink fiasco, which involved the inadvertent commingling of regular corn with transgenic corn not approved for human consumption, also led to studies on the health impacts of genetically engineered foods and recommendations on tightening the regulatory systems (NRC 2004a). Similarly, *Dangerous Liaisons?* (Ellstrand 2003) highlights the concern over gene flow that has dominated public interest in transgenic crops. The National Academies have responded by studying the state of knowledge and making recommendations for strengthening biological containment practices (NRC 2004b). Other areas of institutional adjustment include the need to reduce the potential use of genetic modification for terrorist activities (NRC 2004c).

Under the US approach, agricultural biotechnology products are deemed safe until proven otherwise. The burden of proof lies with consumers. Europe, on the other hand, has sought to introduce a new approach based on the "precautionary principle," which guides the development of biotechnology in the region as well as regulating imports of transgenic products (Raffensperger and Tickner 1999, Morris 2000). The use of the precautionary principle is the subject of extensive scholarly and practical scrutiny (Goklany 2001). Some of the concerns over a science-based system are rooted in the growing rejection of scientific certainty as a way of dealing with social systems (Wallerstein 2004). However, the "risk society" philosophy, as summarized in *World Risk Society* (Beck 1999), inspires much of this. The "risk society" outlook has helped to shift the burden of proof to producers and justify greater government authority to ban or outlaw products on the basis of public concern.

Europe is not the only region to use the precautionary regime; it has also found international expression in the Cartagena Protocol on Biosafety to the Convention on Biological Diversity (CBD) that came into force in 2001. It places more emphasis on the social perception of risk as the foundation for policymaking, in contrast with the science-based approach used by US regulators (Slovic 2000). These perceptions undergo social amplification, which often tends to create illusions of catastrophes (Pidgeon et al. 2003). Ecological concerns are probably the most critical reference point, as illustrated in *Genescapes* (Nottingham 2002). More balanced reviews that include the positive impacts of biotechnology are starting to emerge against this gloomy background (Stewart 2004). Anticipatory environmental impact studies are now being undertaken, as illustrated by studies in Kenya (Hilbeck and Andow 2004).

Despite the differences in regulatory approaches and their market interests, governments are still seen as the ultimate regulators and will continue to play important roles not only in shaping the design of regulatory institutions but also in influencing the direction of technological innovation (Moss 2002).

Socioeconomic issues. Socioeconomic concerns are a central driving force in the biotechnology debate (Evenson et al. 2002). This is mainly because the ultimate expression of the benefits and risks of biotechnology will take socioeconomic forms, even though these benefits and risks are often articulated for political purposes (e.g., as environmental and health issues). Concerns over corporate control of biotechnology and the associated risks drive much of this political activism (Paul and Steinbrecher 2003).

The perceived corporate control of food production, and of plant generation and seed in particular, is associated with the loss of public trust. Some of the loss arises from the close cooperation between academia, industry, and government, the "triple helix" that has been responsible for the rapid adoption of transgenic crops. This cooperation has raised concerns about the risks associated with losing academic independence, as documented in *Science in the Private Interest* (Krimsky 2003), and has resulted in calls for greater moral steering of biotechnology research (Dhanda 2002).

Still more fundamental is the desire to promote community development through local economic development (Norberg-Hodge et al. 2002). What appears as opposition to new technologies may be no more than the clash between local and foreign corporate interests. Opposition to transgenic crops often goes hand in hand with the promotion of organic farming as a competing approach that relies on the appeal to "pure foods" (Ho and Ching 2004). However, the organic farming movement is considered by some to be a continuation of the romanticist revolt against the industrial revolution (DeGregori 2004). In the long run, biotechnology will become indispensable in the production of foods that are safer for human consumption and the environment.

One of the most dominant institutional responses has been a call for stronger regulation of biotechnology and biotechnology firms. In turn, many argue that they are already excessively regulated, even to levels where the potential benefits of biotechnology are likely to be forgone (Paarlberg 2001). Indeed, some have argued that corporations themselves may have brought this about by requesting minimal levels of regulation and thus creating popular concern, especially in the area of biosafety. As noted in *The Frankenfood Myth* (Miller and Conko 2004), the ensuing protests and political activities now appear to threaten the technology itself. In the absence of a capacity to directly curtail the activities of multinational corporations, activist efforts have turned to attacks on the process of technological innovation itself and the specific products sold by the companies (Shiva 2000).

Much of the opposition to biotechnology is more a statement against the perceived risks of globalization than it is a rejection of the associated technologies. If the same technologies were available for local use, they would be treated differently. The focus on specific technologies, however, is guided by the view that multinational corporations not only use innovation as an instrument for international competitiveness but also aggressively promote their protection through intellectual property rights.

Intellectual property rights. Reform in intellectual property laws to allow the patenting of biological inventions is one of the most important institutional innovations associated with the rise of biotechnology (Dutfield 2003). In 1980, the US Supreme Court ruled in the landmark case of *Diamond* v. *Chakrabarty* (447 U.S. 303) that granted intellectual property protection for a live, humanmade microorganism. *Chakrabarty* dramatically altered intellectual property law as it relates to living matters.

An important aspect of *Chakrabarty* was that it purported to overturn the "products of nature doctrine" and to recognize plant life as protectable subject matter under a standard utility patent. *Chakrabarty* entrenched the concept that "anything under the sun which is made by man" is patentable subject matter in the United States. The broad interpretation of patentable subject matter under *Chakrabarty* provided US companies with the promise of patents to protect their investments in new technologies. As a result, US industry greatly expanded its commitment to biotechnology, establishing an early position of world dominance.

The 1980 Bayh-Dole Act (35 U.S.C. 200–212) also accompanied these reforms, which harmonized practices related to the ability of scientists to commercialize products arising from government-funded research (Gross and Allen 2003). The law has been blamed for distorting university research by making it serve corporate interests. But *Ivory Tower and Industrial Innovation* (Mowery et al. 2004) points out that the law simply harmonized existing tendencies for universities to seek intellectual property protection and was not in itself a general impetus for such practices, except in specific areas of life science research. On the other hand, *Innovation and Its Discontents* (Jaffe and Lerner 2004) suggests that the existing patent system has become a barrier to innovation, and needs to be fixed.

The adoption of the Agreement on Trade-related Aspects of Intellectual Property Rights, or TRIPS Agreement, of the World Trade Organization (WTO) helped globalize the legal principles set in the United States (Sell 2003). The agreement seeks to ensure international intellectual property protection by prescribing minimum substantive standards for domestic intellectual property legislation, mandating national enforcement mechanisms, and providing mechanisms for the settlement of international disputes. It specifies the obligation of all members of the WTO to provide patents for both product and process inventions in all fields of technology, if they are new, include an inventive step, and are capable of industrial application.

The emergence of biotechnology has raised awareness that biological diversity constitutes an important source of chemical and genetic material of commercial value. This realization has stimulated bioprospecting activities around the world. But the growth in these activities has also resulted in concern about how developing countries can benefit from the commercial use of biological material in their territories, and about equity in the use of the world's biological heritage. Benefit sharing and access to genetic resources are now the subject of considerable international debate and legislative reform at the national level in many developing countries as part of the implementation of the CBD (Laird 2002).

Guided by this philosophy of competition for resources, the governments of developing countries have aimed to extend sovereign control over biological diversity, which is a key source of input for the biotechnology industry (Rosendal 2000). The CBD confirmed the basic principle of the sovereign rights of states over their natural resources, which includes the authority to determine access to genetic resources through the enactment of national legislation, as carefully documented in *Governing Global Biodiversity* (Le Prestre 2003). The CBD treaty has spurred interest in finding ways to protect traditional knowledge as part of the intellectual heritage of local communities (Dutfield 2004). Much of the work under the treaty, however, has focused on biosafety at the expense of the conservation objectives that inspired the CBD in the first place (Bail et al. 2002).

International trade. The entry of biotechnology into international trade has been greeted with much concern, including the imposition of restrictions on the importation of transgenic products into Europe that have not been approved for commercial use in the region. Environmental concerns have partly inspired these restrictions (Brouwer and Ervin 2002). The associated controversies have focused on the extent to which existing trading rules can effectively balance free trade in agriculture and food safety. On the other hand, some view the global trading system as a mechanism that globalizes hunger (Tokar 2004).

The scope of regulation has come under fire, but the relevance of many of the existing regulatory institutions is now in doubt as well. Regulatory barriers against transgenic crops are emerging because of these concerns. This is true at the national as well as at the global level, as outlined in *Agricultural Biotechnology and International Trade* (Grant 2002). Institutional flux has also created considerable uncertainty about the regulation of biotechnology. Sustained institutional reforms, especially those associated with market liberalization, have created perceptions of laxity in governance systems. International standards-setting bodies such as the WTO have played an important role in prompting safety in international trade (Grant 2002). But their ability to find a balance between international rules and local environmental interests is being questioned (Jasanoff and Martello 2004). Much of the concern arises from the need to acknowledge the importance of ecological interrelations at the local and global levels (Vertovec and Posey 2003).

The process of institutional reform to accommodate emerging technologies does not necessarily require the creation of new structures. The first step would be to adjust existing institutions. It is equally important to ensure that institutions have competencies that match their regulatory tasks. For example, environmental conventions may not be well suited to the task of overseeing human safety aspects of biotechnology. Such institutional misalignment could only increase the prospects of trade disputes over food safety that could undermine the global trading system (Josling et al. 2004).

Developing countries. Technological innovation is a key driving force in economic transformation. Its application in the economy often goes hand in hand with institutional innovation, as shown in *Technology, Growth, and Development* (Ruttan 2001). But transgenic crops are currently limited to soybean, corn, canola, and cotton and are grown mostly in the temperate regions (the United States, Canada, and Argentina). China, Brazil, Uruguay, and South Africa have recently joined the league of producers of transgenic crops (James 2004). The bulk of the crops contain traits for herbicide tolerance and disease resistance. These trends show that the early diffusion of transgenic crops has been largely in the temperate regions, but other regions of the world, such as Asia, are emerging as major actors (Chaturvedi and Rao 2004).

Developments in biotechnology have been associated with significant discontinuities in production methods and institutional structure. The first major discontinuity is the transition from public funding for research to new arrangements that involve greater participation of the private sector (Byerlee and Echeverria 2002). This is affecting international cooperation and making it difficult for foreign firms that hold key technologies to work effectively with local public institutions that have not developed routines such as the management of intellectual property protection (Erbisch and Maredia 2004). International agricultural research institutes have adjusted only slowly to this new culture of innovation and continue to seek ways that guarantee their freedom to operate through flexible systems of intellectual property rights; they view the protection of intellectual property rights as a barrier to the diffusion of essential technologies (Drahos and Mayne 2002). In other words, they argue for a broadening of the public domain (NRC 2003).

Even more fundamental is the past inability of leading international development agencies, such as the World Bank, to establish clear agricultural biotechnology policies. This is mainly because the governance of such institutions is dominated by members of the United States and European Union who do not share a common view on the role of biotechnology in international development. Such uncertainty about policy also affects international development agencies working on agricultural issues. This makes the challenge of building the requisite capacity to take advantage of emerging technologies more difficult (Sagasti 2004).

Despite the existence of genetic options, we have yet to realize the promise of biotechnology to meet the needs of low-income families in the developing world (Thomson 2002). There are two main reasons why we have not realized this promise. First, the public sector has traditionally carried out crop development for low-income families, and the private sector lacks the incentives to invest those biotechnologies that have emerged in crops for low-income families. Second, agricultural research in the public sector has been declining over the years; thus, little investment has gone into developing crops for low-income families (Runge et al. 2003). It is unlikely that the situation will change without a redirection of existing research priorities in private enterprises through the provision of appropriate incentives as well as a significant increase in public-sector funding for agricultural research. In addition, the facilitation of closer cooperation between private and public institutions requires the creation of institutional arrangements.

Efforts to redirect biotechnology to address the needs of low-income families in developing countries should be part of a larger policy framework that addresses other social issues. More important, such strategies should be components of policies designed to use science and technology to achieve sustainable development goals, as proposed in *Ecoagriculture* (McNeely and Scherr 2002). In addition, biotechnology is one of the tools in a larger portfolio of technological options. In this regard, biotechnology is simply a set of tools and the embodied knowledge needed to solve specific problems and create supportive institutions.

This view does not imply that technology is neutral. The choice of technological trajectories often reflects the economic, social, and cultural context from which it emerges. This does not mean that its use always reproduces the same conditions that characterized its origins. Indeed, the techniques of biotechnology embody the flexibility that makes it possible for them to be applied under different farming systems. It is true that biotechnology is currently used mainly in large-scale agriculture in the United States, but the same technology is also being used in small-scale agriculture in China, South Africa, and Kenya. What matters, therefore, is the choice of farming systems.

Redirecting global research efforts to focus on development challenges will entail considerable international cooperation, increases in public funding, and incentives for private enterprise. It will also require the creation of an atmosphere that is tolerant to the use of emerging technologies in implementing sustainable development goals. Nevertheless, where international cooperation is not possible, bilateral responses that might include realignments in international trade relations will become the only option open to countries that view biotechnology as strategic to their mutual interests. Such a scenario is already emerging as countries with strong biotechnology-based industries sign bilateral cooperation arrangements.

Many developing countries are reluctant to engage in biotechnology development because they fear that some industrialized countries would erect barriers against their products. These are real concerns that have created an atmosphere of distrust likely to undermine the global trading system as well as the ability of developing countries to meet their human needs.

Emerging trends suggest that, in the early phases of biotechnology, developing countries are likely to focus their attention toward transgenic crops for local consumption rather than for international markets. This is partly because of the prevailing uncertainty over export markets and because of the preference of biotechnology enterprises for limiting the use of their technology to nonexport uses. Such a trajectory is helping to bring biotechnology in line with the initial expectations of using these techniques to meet human needs. But the extent to which such a trajectory will make a significant difference will depend on other factors, such as the availability of capabilities for technology management. So far, only a small number of developing countries have such capabilities.

Conclusions

The literature outlines the contours of a new world in which advances in the biological sciences influence the design of technological systems and the shaping of social relations. Not only will society benefit from biological technologies, it will increasingly apply biological metaphors in designing new technologies and shaping social institutions. The movement from the mechanistic worldview toward a systemic outlook is not an ephemeral occurrence, but a fundamental transition that, in retrospect, will take on the proportions of a major shift in our worldview.

The emerging literature shows more complex socioeconomic settings that are dominated by the coevolution of technological innovation and institutional adjustment. The studies weave a clear tapestry whose patterns will help guide future research on the emergence of the interactions between technology and institutions in the global economy. Lessons from these experiences will be relevant in addressing policy concerns regarding emerging fields such as nanotechnology and new materials (UN Millennium Project 2005).

Acknowledgments

This article is based in part on sections of my forthcoming book, *Taming the Gene: Biotechnology in the Global Economy.* I am grateful to the Rockefeller Foundation for supporting its background research. I am also indebted to Catherine Verdier for securing many of the books cited in this article, and to Christe S. Bruderlin, Andrea Haffter, and Brian Torpy for additional research assistance.

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