Innovation and Policy against Hunger in a Water-Constrained World**

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Summary
This paper discusses the role of innovation and policy in the fight against hunger in a water-constrained world. The innovations considered here are genetic modification technologies that combine the provision of agronomic benefits to producers with enhanced nutritional value to consumers (i.e., technologies that combine/stack input and output traits). The development of such technologies requires significant resources and is quite often accompanied by the granting of intellectual property rights (IPR) to the innovator(s) involved.

The granting of IPR aims to bolster incentives for research and development (R&D) by providing the innovator with monopoly rights over the new technology. While these rights do increase innovation activity, they can have a significant impact on the price of the new technology and, through this, on the public's access to the innovation.

Understanding that *hunger can be reduced through access to increased quantities of nutritious food offered at affordable prices*, most of the discussion focuses on the effects of different technologies and IPR policies on quantities produced, the quality of production, the prices of food products, and the number of people with access to food in hunger-stricken less-developed countries (LDCs). Once the scientific opportunities and challenges have been identified, the paper highlights some key policy issues shaping the effectiveness of genetic modification innovations and IPR policies in combating hunger around the world.

Current realities
The introduction of genetically modified organisms (GMOs) into the food system and the assignment of IPR for plant genetic resources are among the most notable features of the increasingly industrialized agrifood marketing system of numerous countries, both developed and developing, around the world. IPRs have provided innovating firms with incentives to aggressively pursue improvements of crop characteristics (such as herbicide tolerance, insect and virus resistance, drought tolerance, and increased nutritional value) through gene splicing techniques, and the agronomic benefits of the genetically modified (GM) products have resulted in their embrace by a significant number of agricultural producers around the world.

In particular, 16 years after their initial commercialization in 1996, GM crops were grown on 170 million hectares worldwide with (i) more than half (52%) of those being planted in developing countries such as Brazil, Argentina, India, China, and South Africa; and (ii) a quarter being planted with biotech crops having multiple (i.e., stacked) traits. Seventeen million farmers in 28 countries grew GM soybeans (47% of global biotech area), maize (27%), cotton (14%), and canola (5%) in 2012. GM papaya, alfalfa, squash, rice, and sugar beet were also cultivated on much smaller areas. The market value of biotech crops in 2012 was $14.8 billion, representing 23% of the global crop protection market and 35% of the global commercial seed market.

Intriguingly, in the midst of this so-called gene revolution, about 1 billion people worldwide are facing malnutrition and hunger, with the majority of these people living in water-constrained regions of Africa and Asia. With GMOs and IPR being at the epicenter of innovation activity in the agrifood system, the question that naturally arises is: *Can GMOs and IPR help reduce hunger in a water-constrained world?* This paper argues that they can.

Scientific opportunities and challenges

Scientific research on the effects of genetic modification technologies has focused on the effects of different types of GMOs (e.g., first-generation producer-oriented GMOs, second-generation consumer-oriented GMOs, and, lately, GMOs having stacked both input and output traits) on quantities produced, the quality of production (with the output traits of second-generation GMOs being quality-enhancing), the prices of food products, and the number of people that have access to food. Different regulatory and labeling regimes have been considered within this framework.

The research has identified the potential for significant benefits from the development and adoption of appropriate genetic modification technologies for all participants in the agrifood marketing system. An important message of this literature is that *properly designed genetic modification technologies* (i.e., technologies adapted to the idiosyncrasies and needs of an area) can facilitate production, increase yields, reduce production costs, and enhance the nutritional value of food products.

Key input traits of the GMOs needed in the fight against hunger are *drought resistance* and/or *water-use efficiency* of plants, as water has been a key constraining factor in many hunger-stricken countries. The necessary output traits (e.g., vitamin, iron, or zinc enhancements), will have to be case-specific and dependent on the nutritional needs of different areas.

Important determinants of the effectiveness in combating hunger of these genetic modification technologies are (i) the public attitudes towards GMOs; (ii) the magnitude and distribution of benefits of the GM technology; (iii) the regulatory and labeling regimes governing GMOs (domestically and internationally); (iv) the structure of the agrifood marketing system; (v) the market power of innovating companies; and (vi) the strength and enforcement of IPR in LDCs.

While GM technologies *can* result in increased quantities of nutritious food in hunger-stricken LDCs, there are some major challenges in the quest to utilize such technologies in the fight against hunger. These challenges include (i) the limited availability of suitable GM crops and technologies; (ii) the limited capacity for R&D in most LDCs; (iii) the role of NGOs in shaping public attitudes towards GMOs; (iv) the trade relationships of LDCs with countries hostile to GMOs; and (v) the inefficiency of the regulatory system in most LDCs.

Research in the area of IPR enforcement has focused on the effects of different IPR enforcement policies and strategies on the prices and adoption of new technologies, the level of output produced, and the number of people with access to the relevant innovation(s). Different objectives of innovators and governments involved have been considered within this framework.

The level of IPR enforcement has been shown to affect the welfare of the interest groups involved (i.e., producers, consumers, and innovators), and has important ramifications for the pricing and adoption of the new technology. Specifically, the weaker the enforcement of IPR in a country, the lower the price of the new technology, the greater the technology adoption by producers, and the more consumers who have access to this technology. Since the price of the new technology is inversely related to the level of IPR enforcement, lax IPR enforcement also increases the international competitiveness of domestic producers utilizing this technology (by placing producers in countries where IPR are more effectively enforced at a cost disadvantage). While lax enforcement of IPR can benefit *all* biotechnology users in an LDC, it reduces the innovators' rents by diminishing their ability to obtain value for their biotech traits.

Since weak IPR enforcement benefits the LDC producers and consumers while reducing the rents accruing to the innovator(s), the level of enforcement in the LDC will be determined by the political preferences of the government and the weight it places on innovator rents. The less importance the domestic government places on (usually foreign) innovator rents, the lower the level of IPR protection. Factors affecting the importance the domestic government places on innovator rents (and, thus, its enforcement policy) include (i) the political influence of the innovating firm in the LDC; (ii) the bilateral relationship with the country of origin of the innovating firm; (iii) the severity of the sanctions in the case that the LDC is successfully held to have imperfectly enforced the innovator's IPR; (iv) the conjectures of the domestic government regarding the effect of its enforcement policy on the future development of (and domestic access to) new technologies; (v) the role of NGOs in shaping IPR policies (e.g., by challenging patents and lobbying for certain provisions); and (vi) the size of the enforcement costs.

It is important to note that, while the above discussion (and most of the relevant literature on the topic) assumes that innovators desire the strong enforcement of their IPRs, there might be cases that the innovating firms find it optimal to not enforce their IPR in hunger-stricken LDCs. In fact, there could be cases that innovators find it optimal to provide free access to their new technology in these countries. For instance, if this enforcement strategy increased the innovator's goodwill in the LDCs (that get the technology for free) but also in developed countries (that can now associate the innovator *and* the innovation with a noble humanitarian endeavor), the benefits to the innovator could easily outweigh the lost royalty fees from these LDCs. If done correctly, such an IPR strategy could result in significant benefits for hunger-stricken LDCs, the innovating firms, *and* the image of (and public attitudes towards) agricultural biotechnology as a whole. The latter could be particularly important in places like the European Union where the consumer opposition to GMOs has shaped the regulatory response to these organisms with significant ramifications for many hunger-stricken LDCs trading with the E.U.

Policy issues

Since GM technologies can play a significant role in the fight against hunger, it is important to consider the key issues affecting the development of appropriate genetic modification technologies, and the adoption of such technologies in hunger-stricken LDCs.

- Stacked genetic modification technologies, which combine drought resistance and water-use efficiency of plants with quality enhancing attributes relevant to the nutritional needs of the local population, need to be developed. This development must be done by innovating firms and universities with relevant expertise, in collaboration with local experts. If possible, this work should be done domestically in the countries of need and/or at appropriate facilities abroad, with funding for research, capacity building, and training of local scientists provided by government programs (e.g., United States Agency for International Development, National Science Foundation, U.S. Department of Agriculture), the World Bank, major foundations and philanthropists, and NGOs.

- The adoption of new technologies will require a change in public attitudes towards GMOs. This can be achieved by local universities and research stations, government agencies, and NGOs providing information about the potential benefits of relevant GM crops.

- Enhancing technology adoption and consumer access to new food products can also be facilitated by reduced prices for these products. In hunger-stricken LDCs, this can be achieved by lax or no enforcement of IPRs, coupled with R&D subsidies and/or public R&D.

- Efficient regulatory systems are needed to evaluate new innovations in a timely manner.