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The Effects of Biotechnology Policy on Trade and Growth*

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Despite the clear influence of European Union biotechnology restrictions on trade patterns, very little work has been done to model these influences or their long-run effects. This paper presents an economic trade theory model of biotechnology, biotechnology research and development (R&D), and biotechnology regulation. The model analyzes the impact of European Union consumer preferences on production and consumption of biotechnology products, the level and national origin of biotechnology R&D, trade patterns, and growth. The results indicate that developing countries may become the major producers of biotechnology agricultural products if they can establish the necessary legal infrastructure; and that European biotechnology regulations effectively act as a capital subsidy to developing countries.

Keywords: biotechnology, economic growth, international trade, regulation, research and development

1. Introduction

The most important current influences on agricultural trade patterns are the advent of biotechnology and the European Union (EU) stance against biotechnology products. For example, in 1996 Argentine soybean production was 11.2 million metric tons (t), of which 0.75 million t were exported. The advent of transgenic soybeans helped boost production to 19.5 million tons and exports to 3.2 million in 1997, making Argentina the third largest exporter of soybeans in the world; exports increased further to 5.8 million t in 2000 (USDA). In contrast, in 1997 the United States exported 1.6 million t of corn to Western Europe; in 2000 the United States exported less than 0.1 t to Western Europe because of restrictions against the importation of transgenic crops (USDA). As additional biotechnology innovations are commercialized and used, additional sea changes in trade patterns can be expected.

A plethora of discussion papers on biotechnology and the EU are available in the non-technical literature, but the trade literature contains almost no models of the impacts of biotechnology regulation on trade patterns or economic growth. Gaisford and Lau (2000) provide what is perhaps the seminal model of the economic impacts of EU restrictions on biotechnology products, arguing that allowing consumers to choose between transgenic and traditional agricultural products is preferable to embargo-like restrictions on the importation of transgenic products. While the static, partial-equilibrium approach of Gaisford and Lau is a significant first step, it is imperative to introduce global dynamics into models of evolving biotechnology and trade patterns.

To provide a richer understanding of emerging trade patterns, we present a dynamic trade theory model of biotechnology, biotechnology research and development (R&D) and biotechnology regulation, and a discussion of some legal aspects of biotechnology trade. Our paper is similar in spirit to that of Gaisford and Lau, but extends coverage in four important ways. First, we use a general-equilibrium trade model as the point of departure. Second, our model includes both consumers' concerns about biotechnology and the impact of biotechnology on agricultural production; in contrast Gaisford and Lau do not allow for supply or other shifts in response to cost-saving biotechnologies (see their technical appendix). Third, we include developing countries in the model: accurate examination of biotechnologically induced supply shifts is incomplete without examination of how these countries may respond to emerging opportunities in biotechnology. Fourth, we take a dynamic approach to modeling the consequences of biotechnology on trade patterns and

economic growth. Biotechnology is an emerging and continuing phenomenon that is expected to affect agricultural and economic growth over the foreseeable future.

In this paper we modify the Hecksher-Ohlin model (see Dixit and Norman, 1990) to include endogenously determined levels of R&D activity. The R&D activity induces economic growth in Schumpeterian fashion (see Dinopoulos, 1994 for a discussion), through a quality-ladders type approach (see Segerstrom, Anant and Dinopoulos, 1990; Grossman and Helpman, 1991; or Aghion and Howitt, 1992, for pioneering work on quality ladders). Dinopoulos, Oehmke and Segerstrom (1993) first extended the Hecksher-Ohlin framework to allow for R&D-based quality improvements and economic growth in a North-North framework. We extend their model to include developing countries and adapt it for application to biotechnology.

The paper proceeds by developing the model in section 2, and interpreting it in section 3. Section 4 considers the relationships between institutional and legal structures and trade patterns, based on model results. The final section draws conclusions.

2. A North-North-South Trade Model with Biotechnology

Here we provide a brief description of the trade model. Further detail and graphical exposition of the model is contained in the technical appendix. We consider a model with three trading blocks, differentiated by their relative R&D capabilities, capital/labour ratios, and regulatory policies relevant to biotechnology production and consumption. North America (N) and Europe (E) constitute the two "North" trading blocks; following the trade literature the "South" trading block (S) represents developing countries. The driving forces behind Hecksher-Ohlin-type models of trade patterns are factor endowments and the factor proportions in sectoral production. We assume that the two North trading blocks, N and E, have high endowments of capital relative to their labour endowments, and that the S endowment is relatively high in labour. In referring to labour, we are referring primarily to the unskilled component of labour inputs; in referring to capital, we are referring both to physical and human capital inputs. N and E also have the technical capacity to undertake biotechnology R&D, but S does not. The difference between N and E is that N produces and consumes biotechnology products, but E has regulations that effectively prohibit either production or consumption of these products. Even though biotechnology products are not technically prohibited, European Union regulations for import and marketing are so restrictive as to be *de facto* prohibitions (see Perdikis,

2000, for details). Neither S nor N prohibits the production or consumption of biotechnology products.

Three productive opportunities exist: biotechnology R&D, production of biotechnology goods, and production of outside goods. The outside-goods sector includes traditional (non-biotech) agricultural products; for simplicity we assume that the outside-goods sector does not experience innovation. The biotechnology sector is represented by those goods that can be replaced by new goods of higher quality through innovation resulting from R&D activity. The level of biotechnology R&D determines the rate of innovation in the biotechnology goods sector. We assume that biotechnology innovation contributes positively to the economy; alternative views are discussed in section 4. Each trading block has the option of allocating the two factors of production, capital and labour, across the productive opportunities available to the block. The E and S blocks are restricted in their factor allocations by regulation and technical capacity, respectively.

We further assume that R&D is the most capital-intensive sector, followed by biotech goods production and then the outside-goods sector. The assumption that biotech production is more capital intensive than outside-goods production is consistent with the high value of durable assets relative to labour in developed agriculture (here we include land, buildings and farm equipment as part of capital), and with agricultural biotechnology being even more capital intensive than non-biotech agriculture. As with most Hecksher-Ohlin models, it is straightforward to show that there is a set of endowments that allow capital rental rates and wages to equalize across trading blocks; we restrict our attention to this set (Dixit and Norman, 1990).

In the initial equilibrium, E produces R&D and outside goods, but consumes only outside goods. Regulations prohibit the consumption of biotechnology goods, and biotechnology R&D is consumed only through production of the biotechnology good, which is also prohibited. Moreover, because E is not importing biotechnology goods, the factor content of E's imports will be more labour intensive than if E had no restrictions on biotechnology.

S produces outside goods, and biotechnology products, using rented technology imported from E or N. S pays for the rented technology by supplying outside goods to the rest of the world. Since S has labour-intensive endowments, it also is a net importer of biotechnology products. N produces all three products, but has a comparative advantage in the more capital-intensive R&D and biotechnology-product

sectors. N is a net exporter of R&D and biotechnology products, and a net importer of outside goods.

We allow for the impact of technical change on factor efficiency by considering effective factors of production. An effective factor of production is a factor of production that is measured by both its physical characteristics (e.g., one word processor) and by the efficiency with which that factor is used (e.g., one word processor is n>1 times as efficient as a manual typewriter). We refer to factors measured in efficiency units as effective factors of production.

The impact of technical change caused by biotechnology R&D is to increase the efficiency of those factors used in the production of biotechnology goods. This in turn increases the endowment of effective factors of production for those trading blocks producing biotechnology goods, N and S. Since biotechnology production is relatively capital intensive, this increases the effective capital intensity of the N and S endowments, i.e., the capital intensity measured in effective factors.

The most striking dynamic effects of biotechnology on trade patterns arise when examining the increases in N's and S's effective endowments. As N and S continually adopt the latest innovations in their biotechnology production, their effective endowments become more and more capital intensive. This leads them to reallocate factors to the production of the more capital-intensive goods, that is R&D and biotechnology goods. This suggests that E will become increasingly less important as a provider of biotechnology R&D, and that if S chooses to develop the institutional and technical capacities, it may eventually become a significant force in biotechnology R&D.

The implications for economic growth and growth dynamics from this model are truly revolutionary. S becomes more capital abundant at the expense of E. Once again, this occurs because E prohibits the production and consumption of agricultural biotechnology products, which negates any possibilities for it to obtain rents from this technology. In addition, as E becomes more labour intensive and consumes more labour-intensive goods, the amount of trade with the rest of the world is expected to decrease. Hence, E will realize lower agriculturally related GDP growth. The clear winners from biotechnology and the European policy are the producers and consumers in the South. The overall impact on N is less clear: N gains from accessing biotechnology, but E-N trade is diminished by the policy. What is clear is that S and N will continue to produce biotechnology goods and trade will expand between those two regions.

3. Interpretation of the Model Results

In many ways the model is highly stylized, and thus results must be interpreted with care. For example, since the model neglects technical innovation in the non-agricultural sector, we should not conclude that the absence of biotechnology production and consumption will cause Europe to slide into a technologically backward, slow-growth economic situation. However, a reasonable interpretation is that the biotechnology restrictions will cause European *agriculture* to become relatively stagnant, both technologically and in its contribution to trade and growth, mitigating the positive effects of technological opportunities and advances in other sectors. (This does not preclude Europe from specializing in products unique to non-biotechnology agriculture, such as organic foods; however, at this time there is no reason to believe that these markets are more than niche markets.) A second issue relates to development. As promising as biotechnology is, we do not expect biotechnology by itself to propel developing countries into becoming major economic powers. A realistic interpretation is that the model shows that biotechnology, and the European consumers' attitudes toward biotechnology, provide developing agricultural economies with a unique opportunity for technological progress, increased trade, and faster economic growth. However, developing countries must be ready to make investments in technical capacity and to put into place the legal infrastructure necessary to take advantage of this opportunity. We return to this issue in the next section.

The following important and robust results emerge from the model.

- Restrictive European biotechnology policies diminish the effective growth rate of their capital stock.
- Restrictive policies lead to a decline in European agricultural growth and trade.
- The lack of European agricultural biotechnology production provides the South with an enhanced opportunity to engage in biotechnology production and trade.
- The South has an expanded opportunity for effective capital accumulation and increased economic growth.

4. Model Results in the Context of International Law: Implications for North and South

The model suggests that developing countries have an opportunity to increase agricultural productivity and agriculture's contribution to economic growth by acquiring (importing) agricultural biotechnologies from the North. However, this

requires developing and adopting appropriate biosafety and food safety regulations, and intellectual property protection (IPP), each of which is increasingly governed by international law.

Similarly, an expansion in biotechnology R&D and product exports from North America depends on the scope and efficiency of the IPR and biosafety legislation implemented in the South, which will be its primary export market. Recent adoption of the international biosafety protocol (known as the Cartegena Protocol on Biosafety) by delegates of 128 parties to the Convention on Biological Diversity has serious implications for international law governing the trade of genetically modified organisms (GMOs), and may affect the exports of biotechnology products from the United States and Canada. Similarly, the extent of the technological stagnation of agriculture and trade predicted for Europe, as represented by E in the model, depends on the influence consumers will continue to have on the EU's agricultural and trade policies.

Below we discuss some of the recent developments in international law that govern the IPP, biosafety and food safety aspects of biotechnology research and output, and their implications for trade and economic growth in the North and South.

Intellectual Property Protection (IPP)

In the United States, the Plant Patent Act of 1930 and the Plant Variety Protection Act of 1970 provide *sui generis* protection of intellectual property residing in plants. In Diamond v. Chakrabarty the U.S. Supreme Court allowed protection of living tissue via utility patents; ensuing case law and PL 98-620 extended this protection to genetic material. Currently, utility patent protection is available to inventors of genetic sequences, biota incorporating patented genetic sequences, and the processes for discovering genetic sequences and transferring them across biota. Canada and the European Union provide similar IPP. The South does not yet have this level of IPP. Consequently, it appears that they do not yet have the legal infrastructure necessary to commercialize biotechnology discoveries that they make. In many cases, developing countries do not have the IPP needed to import biotechnologies, preventing development of competitive biotechnology-product and biotechnology-R&D industries.

The international law related to developing-country IPP derives in large part from the Trade-Related Aspects of Intellectual Property Rights (TRIPs) agreement, a legally binding agreement under the World Trade Organization (WTO). Article 27.1 of the agreement requires members to provide patents "for all inventions, whether

products or processes, in all fields of technology". Article 27.3(b) allows the exclusion from patentability of plants and animals but not microorganisms. This is interpreted to mean that isolated or purified proteins and isolated DNA sequences that code for certain proteins are protected (Maredia, 2001). Article 34.1 places the burden of proof in process patents on the defendant to show that the patented process is not used in production. For the first time in any area of international law, the TRIPs agreement regulates enforcement and redress (Maredia, 2001). Disputes as to the compliance of IPP regulations are subject to the WTO's binding dispute procedure. A non-compliant WTO member may be subject to trade sanctions.

The TRIPs agreement seemingly provides sufficient IPP for agricultural biotechnology to be invented and/or used in developing countries. However, the enforceability and strength of this protection are as yet untested. Thus we do not know, for example, to what extent the WTO will act to protect the intellectual property of a patented genetic sequence that is part of a plant grown in a developing country that chooses not to recognize plant patents. Further, the TRIPs agreement allows member countries to use a *sui generis* system of protection in place of recognizing biotechnology patents.

Currently, many developing countries are moving toward adoption of patents or other forms of IPP protection for biotechnology. In 1998, The Indian Council of Agricultural Research created a new unit exclusively for issues dealing with IPP based on Indian patent law (Mishra, 1999). Indonesia has created an office solely for dealing with IPP issues, subsidiary to the Ministry of Agriculture (Maredia, Erdisch and Sampaio, 2000). In Egypt, the Agricultural Genetic Engineering Research Institute (AGERI) has recently established an Intellectual Property and Technology Transfer Office (Maredia, 2001). As members of the Union for the Protection of New Varieties of Plants, Argentina, Bolivia, Brazil, Chile, China, Colombia, Israel, Kenya, Mexico, and South Africa have effective plant variety protection; Korea and Thailand have protected plant breeders' rights. Argentina, Brazil, Chile, China, Korea, Mexico, and South Africa have amended their patent laws or developed new patent legislation to cover microorganisms, microbiological processes and microbial processes. These regulatory advances are usually the result of interest in protecting national intellectual property and developments, but such property is often discovered with support from public or private organizations in developed countries. For example, about one-half of AGERI's transgenic potato trials are the result of collaboration with Michigan State University; AGERI also has a partnership agreement with Pioneer Hi-Bred

International (Maredia). The upshot is that developing countries are increasingly protecting biotechnology IPP.

As a result of developing-country investment in legal infrastructure and other capacity, several indicators suggest that an increasing proportion of the world area planted to transgenic crops may lie in these countries. Among these indicators are China's exhibition of strong interest in biotechnology, Brazil's efforts to develop biosafety protocols and intellectual property protection (spurred in part by the need for Brazil's soybean industry to remain competitive with Argentina's), and the development of "golden rice" for use particularly in Asian rice-based economies. "In 2000, four countries grew 99 percent of the global transgenic crop area. It is noteworthy that they are two industrial countries, USA and Canada, and two developing countries, Argentina and China" (James, 2000). The proportion of transgenic crops grown in developing countries increased steadily from 14 percent in 1997 to 24 percent in 2000 (James).

If Europe does not produce transgenic crops it is possible and even probable that the majority of the area planted to transgenic crops will lie in developing countries, as suggested by the model. As developing countries adapt biotechnology advances to their specific agroclimatic conditions, it is possible that they will become the dominant producers in terms of quantity and value. However, this outcome is strongly dependent on the ability of developing countries to put in place IPP that meets WTO standards and the needs of the private sector.

Biosafety and Food Safety Policies

Biosafety and food-safety policies are components of the infrastructure necessary to produce biotechnology products. Multinational biotechnology companies, some with already damaged reputations, are leery of selling products to countries without adequate safety regulations. The desire for biosafety and similar regulation arises from a variety of concerns:

Food Safety Risks

Particularly given Europe's ongoing experience with "mad cow" disease, European consumers are concerned with long-term and chronic effects of untested foodstuffs. A related issue is that transgenic manipulation would increase allergens, either through unintended transmission or because the nature or level of the transgenic characteristic is itself an allergen.

Environmental Pollution

The debate continues as to whether herbicide-tolerant crops will increase or decrease the overall use of herbicides, and to what extent insect-resistant crops harm beneficial insects. The likelihood and effects of genetic pollution via gene escape, and the potential emergence of "superweeds" that out-compete indigenous plants, are as yet unquantified.

Risks to Agricultural Production

A primary worry is gene escape, especially resulting in greater resistance among unwanted species to insecticides and herbicides. Some groups speculate that overuse of transgenic varieties will result in the loss of temporal and spatial biodiversity within crop gene pools.

Moral Concerns

A major concern expressed in public surveys and the media is a perception that crop genetic modification is an unnatural, insufficiently tested technology. GMO crops do bring together new gene combinations that do not exist in nature, and this fact is the basis of some of the reservations of those opposed to genetically modified crops and stricter standards for biosafety policy.

While developed countries in North America and Europe have established domestic biosafety and food safety regimes, many developing countries are only now starting to establish their own national systems. The food safety standards, guidelines, and other recommendations of the Codex Alimentarias Commission (CAC)[1] are explicitly recognized under the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). To conform to international trade laws, developing countries that are members of the WTO will have to adhere to the CAC food safety standards and guidelines and meet the SPS Agreement in developing their national food safety policies.

The Cartagena Protocol on Biosafety (CPB) provides minimum standards for biosafety regulations to be implemented by all ratifying countries. The CPB seeks to protect biological diversity and food safety by embracing the precautionary principle,[2] and puts the environment on par with trade-related issues in the international area. Specifically, in the case of insufficient relevant scientific information and knowledge, a country may decide to apply the precautionary approach and refuse the import of the GMO into its territory. The CPB also recognizes the right of importing countries to take into account socio-economic considerations, such as the value of biological

diversity to its indigenous and local communities, in reaching a decision on import of GMOs. Through November 2000, 80 countries, mostly from the European and "South" trading blocks, have signed the CPB. These signatories include Argentina, the second biggest GMO exporter, and other potential exporters such as China, Indonesia, and the Philippines.

At issue is nothing less than the future of trade in agricultural biotechnology products. If a number of South countries use the CPB to restrict trade in biotechnology products, export markets for biotechnology products may never develop. This would greatly restrict possibilities for economic growth through trade, especially for agriculturally based developing countries. It would also have negative implications for the expansion of production and exports of biotechnology products in the United States and Canada.

Regulations Regarding Labelling of GMOs

The CPB requires the type of mandatory labelling already demanded by the EU and Japan. The majority of the emerging biosafety laws in developing countries adhere to the European concept of mandatory labelling. There are several important issues related to labelling.

The first important issue is whether GMO testing should be required. Some countries have specific procedures required to market foods made in part or whole from genetically modified ingredients, and require labelling of all such foods as genetically modified, with a specification of what the modification does. It is an open question as to whether countries that wish to export crops or foodstuffs will have to meet the importer's requirements for labelling, and if so, will they have to provide test results supporting their labels? Will this, or any similar, requirement be regarded as a trade barrier in contravention of the WTO?

The second important issue is whether labelling of foods improves social welfare. Allowing growers the choice of what type of crop to produce means that costly segregation of genetically modified (GM) from non-GM crops throughout the supply chain is critical to accurate labelling and sales. Gaisford and Lau (2000) suggest that if the perceived quality difference between GM and non-GM crops is large, then labelling of GM crops is a better choice than an import embargo. A related question is: Should labels apply to the GM crops, or to the non-GM crops, and who should bear the costs of certification and labelling?

Finally, there is an issue of consumer acceptance of labelling. In the EU, the Safeway/Sainsbury episode suggests that even labelling of GM foods is not supported

in the marketplace—labelling of individual items is trumped by the labelling of entire supermarkets as GMO free! If this continues to be the case, then questions of appropriate product labelling may be moot.

5. Conclusions

The addition of growth dynamics to a model of biotechnology trade generates a fascinating new set of implications. The dynamic model shows that Europe's policy on prohibiting the production and consumption of agricultural biotechnology products slows European agricultural and economic growth. As North America and the South continually adopt the latest biotechnology innovations, their effective endowments become more and more capital intensive. This leads them to reallocate factors to the production of the more capital-intensive goods, that is, R&D and biotechnology goods. This suggests that the South will eventually become a significant force in biotechnology R&D, and Europe will become increasingly less important as a provider of biotechnology R&D. Europe becomes relatively more labour intensive, and consumes more labour-intensive goods, which has a negative effect on European trade with the rest of the world. The non-adoption of biotechnology innovations and the diminished trade confirm the relative stagnation of agricultural growth in Europe.

In order for developing countries to take advantage of the unique opportunities for technological progress, increased trade and faster economic growth, they must invest in technical capacity and put in place the legal infrastructure necessary to import and/or develop biotechnologies. Competitiveness will require the developing countries to adopt and enforce appropriate biosafety, IPP, and food safety regulations. Currently, many developing countries are moving toward adoption of patents and other forms of IPP for biotechnology. This movement of investing in legal infrastructure, and the fact that increasingly a greater proportion of the world area planted to biotech crops lies in these countries, support the results of the model.

Despite the fact that biotechnology is expected to have an effect on agriculture as large or larger than the Green Revolution, little work has been done on the effects of biotechnology and biotechnology regulation on trade patterns. The dynamic approach taken in this paper shows that these effects may indeed be much larger than is generally accepted—so large as to engender a stagnation of European agriculture relative to North American agriculture, and possibly to agriculture in some developing countries.

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Endnotes

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[1] CAC was formed in 1962 to implement the Joint FAO/World Health Organization Food Standards Programme. Its purpose is "to protect the health of consumers and ensure fair practices in the food trade".

[2] The essence of the precautionary principle is that it is better to err on the side of caution and not introduce new (i.e., transgenic) foodstuffs unless they have been thoroughly tested and found to be safe. For good discussions see Kerr (1999) or Caswell (2000).

The technical annex to this paper, pages 297-306, is available separately.