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Biotech and Planted Trees: Some Economic and Regulatory Issues

Roger A. Sedjo
Senior Fellow and Director, Forest Economics and Policy Program, Resources for the Future, Washington, DC

In recent years, the application of biotechnology to agriculture has resulted in a host of changes and innovations. Transgenic (genetically modified) crops are now common in much of North American agriculture. Transgenic forestry is not yet at that level of commercial application. However, there are numerous biotechnological innovations under development in forestry, many of them adapted from agriculture. This paper provides an introduction and background into transgenic trees and forestry. It then discusses some aspects of the economic potential and the regulatory system related to transgenic trees.

Key words: biotechnology, transgenics, trees, genetic engineering, timber, fiber, genes, economics, industrial wood, GMOs, plantations.

Overview

Genetically modified (GM) or transgenic trees are approaching commercialization in forestry. For thousands of years, humans utilized forests as a source of materials used for producing objects and providing shelter, fuel, food, fiber, medicinal plants, and so forth, giving no thought to the forest's regeneration. Natural processes were largely capable of restoring the minor damage that humans occasionally inflicted on the forest. Only gradually, as human economic activity increased, were larger volumes of wood required. Over the past fifty years, forestry has begun to experience a serious transition—from the gathering of the wood commodity provided by a wild resource and created by natural processes to the cropping and growing of planted forests—much like with other agricultural crops. As with agriculture, the forest crop is harvested periodically and subsequently replanted for future harvest. Of course, the time scale for forestry is longer than the typical agricultural crop.

Plantation forestry has tended to be of two types. Traditional plantation forestry involved the planting of indigenous species. This type of forestry has been common in much of Europe, Japan, and North America. More recently, plantation forests have involved the planting of exotic species. This has been a particularly common practice in subtropical regions of South America, parts of Africa, and Asia. Often these are fast-growing commercial species—various pine from North America or eucalyptus from Australia. Important examples of the introduction of more temperate species include radiate pine in New Zealand, Australia, and Chile, as well as other temperate species in Argentina and Uruguay. Eucalyptus and Caribbean pine are planted on appropriate sites in more tropical regions, and US southern pines are grown in the more subtropical parts of South America.

Initially, many plantations involved simply the planting of seedlings with minimal subsequent management beyond protection. In later rotations, however, more intensive management has often been applied during the growing period. In the southern United States, for example, recent studies have shown that the productivity and financial returns to additional management can be substantial (Yin, 2001). Major sources of increased productivity and returns in forestry have been breeding programs and vegetative control at the time of planting.

Although planted forests are not new, the transition of forestry from foraging to an agricultural cropping mode has been underway on a truly global scale only within the past half century or less (Sedjo, 1999). Only during the past two decades have industrial plantation forests become a significant supplier of industrial wood, which is now becoming a significant substitute for wood obtained from natural forests. The reasons for this change include the long-term rise in industrial wood prices, the increasing inaccessibility of natural forests suitable for harvests, and the potential for large productivity increases associated with the improved provision of inputs to planted forests. Various technological innovations have contributed by decreasing the relative costs of wood from plantation forests vis-a-vis natural forests. Also, pressures by environmental activists have reduced the potential harvest from old-growth and natural forests.

Once the forests began to be regenerated by human activity, it made economic sense to try to improve the quality of seed stock used in forestry, just as it had in

Table 1. Estimated global industrial wood harvests by forest management condition, circa 2000.

Forest management condition[a]	% of global harvest
Indigenous second growth, managed	30
Industrial plantations, indigenous	24
Old growth	22
Second growth, minimal management	14
Industrial plantations, exotic	10

Note. Data from Sedjo (1999).

[a] Old growth includes Canada, Russia, and Indonesia/Malaysia and is adjusted for harvest declines after the demise of the Soviet Union. Second growth, minimal management includes parts of the United States, Canada, and Russia. Industrial plantations, indigenous includes the nordic countries, most of Europe, a large but minor portion of the United States, Japan, and some from China and India. Indigenous second growth, managed: residual.

agriculture. Activities are underway to try to plant improved (or superior) trees, rather than maintaining the same unimproved seed stock. In forestry, as with other agriculture, economic incentives for investments in plant domestication, breeding, and plant improvement activities occur when the investor can capture the benefits of the improvements and innovations. Early plant improvements involved identification of superior trees with desired traits. In recent decades, traditional breeding techniques have been practiced in forestry. Since the 1990s, modern biotechnology—including tissue culture and genetic engineering—has been developed in earnest in forestry.

Forest Plantations Today

Table 1 presents a recent estimate of the volume of industrial wood provided by various types of forests. Today it is estimated that about 34% of the harvest comes from planted forests and 10% from exotic forests in the tropics and subtropics. By contrast, harvests from planted forests in 1950 were negligible. However, the percentage coming from planted forests (especially exotics in the tropics and subtropics) is likely to rise substantially during the first half of the 21st century. The Food and Agricultural Organization of the United Nations (FAO) estimates that the percentage of planted forests could rise to 50–75% of the world's industrial wood needs by the year 2030 (FAO, 2000).

A quick reconnaissance of some of the recent experiences of plantation countries might be of interest.

The United States. In recent years, 2.5–3.0 million acres (about 1.0–1.2 million ha) have been planted annually in the United States. This amounts to the planting of 4–6 million seedlings each day over a 365-day year. In the 1990s, roughly 70% of the total planting was in the South and 84% of the total was on private lands (e.g., Moulton & Richards, 1993).

New Zealand. New Zealand has about 1.3 million ha of industrial plantation forests. Although the establishment of new forest was reduced to 10–20 thousand in the early 1990s, planting for 1994 is estimated at a record 130 thousand ha, due in part to the very strong international prices in 1993 and 1994. Recently, planting has declined due to weak international markets. It is estimated that another 3–4 million ha of land are potentially available for industrial plantations, most of it from sheep pasture, which has been in decline for decades due to weak market prices.

Chile. Chile has become a major focus of plantation establishment and production (Clapp, 1993). During the 1990s, plantation establishment fluctuated between 50–100 thousand ha annually. Associated with this has been the development of both a pulping and a solidwood industry.

Argentina. Argentina has about 800,000 ha of industrial forest plantations and plans for the planting of about 400,000 additional ha. Argentina's growing conditions are quite good, and large amounts of low-cost land are potentially available for industrial forest plantations. A major drawback with some of the Argentinean sites is their distance from major markets and a weak transport infrastructure.

Brazil. Large areas of Brazil (mostly degraded agricultural lands) have been converted to plantation forests over the past several decades, especially since the late 1960s. During the 1970s, annual plantings often exceeded 500 thousand ha; Brazil is estimated currently to have some 6.5 million ha in plantation forest. The potential for additional plantations is great, both in terms of land area available and also given the high growth experienced in many Brazilian forests. Although the Jari project in the Amazon has received much notoriety, the greatest potential for plantations remains largely in the semitropical region in the south of the country.

Table 2. Worldwide annual growth in consumption of industrial wood, 1950–1985.

Period	Production/consumption (%)
1950–1960	3.34
1960–1970	2.20
1970–1980	1.10
1980–2000	0.34

Note. 1950–1980 data from Sedjo and Lyon (1990, p. 56). 1980–2000 data from Food and Agricultural Organization of United Nations (2004).

China. Tree planting in China is proceeding on a large scale. Substantial areas of both industrial forests and conservation/protection forest have been established. China has been reported to have planted well over 1 million ha annually for the past two decades. China, surprisingly to many, is the world's fourth major industrial wood producer.

Industrial Wood Markets

Table 2 presents global production/consumption of industrial roundwood over the past five decades. The rate of worldwide wood consumption growth has declined gradually but consistently over the past half century. Hence, the lack of growth in worldwide consumption (and production) of the past two decades can be viewed as consistent with the long-term gradual reduction of consumption/production growth toward zero (or perhaps even future negative values).

Despite the large increases in global economic activity, wealth, and population over the past two decades, the total consumption of industrial wood has barely changed. Note that although this period experienced some minor economic downturns, a major characteristic of the period was widespread economic growth, including the emergence of China and other countries in Asia as important economic powers. Nevertheless, worldwide production (and consumption) was essentially flat over the most recent two-decade period.

Most analysts believe that demand in 2050 will be near 2 billion cubic meters, or roughly a very conservative one-third increase above current levels over the next 50 years. Victor and Ausubel (2000) provide a range of 2–2.5 billion but lean toward the lower estimate of 2 billion.

This view of very slow growth is supported by a recent comprehensive analysis and projection of global timber supply by Sohngen, Mendelsohn, and Sedjo (1999), who estimate global timber production of about 2.0 billion cubic meters for 2035. The study projects that industrial wood real prices (adjusted for inflation) will rise over this period, but only very modestly. Furthermore, Sohngen et al. (1999) project the harvest level by three types of forest. These projections indicate that the portion of total harvests provided by plantations accounts for all of the increases in the world's harvests over that period, whereas harvests from traditional second growth and old growth are small and declining both absolutely and relatively.

Table 3. Gains from various traditional breeding approaches: loblolly pine.

Technique	Effect
Orchard mix (open pollination, first generation)	8% increase in yields
Family block (best mothers)	11%
Mass pollination (control for both male and female)	21%

Note. Data from personal communication, Westvaco Corporation researchers, June 10, 1998.

Tree Improvement

Tree improvement most often has relied on traditional breeding techniques like selection of superior and candidate trees for volume and stem straightness and grafting these into breeding and seed-producing orchards. When breeding orchards begin to flower, pollination of selections is artificially controlled, seeds are collected, progeny tests are established, and the best offspring are chosen for the next cycle of breeding. By identifying and selecting for desired traits, breeding can select for a set of traits that can improve wood and fiber characteristics, improve the form of the tree, improve growth, and provide other desired characteristics. These traits are introduced into the genetic base that is used for a planted forest. This contributes to the more efficient production of industrial wood and to an improved quality of the wood output of the forest. In the past, operational quantities of seed from production seed orchards were derived from open pollination. Today, however, more sophisticated, large-scale, controlled pollination techniques are in place, which offer the potential of further improvement of the offspring of two superior parents.

The results of traditional breeding approaches to improve tree yields serve to illustrate the possibilities of traditional breeding (Table 3). For most tree species, the typical approach involves the selection of superior trees for establishment in seed orchards. Experience has shown that an orchard mix of first-generation, open-pollinated seed can be expected to generate an 8% per gen-

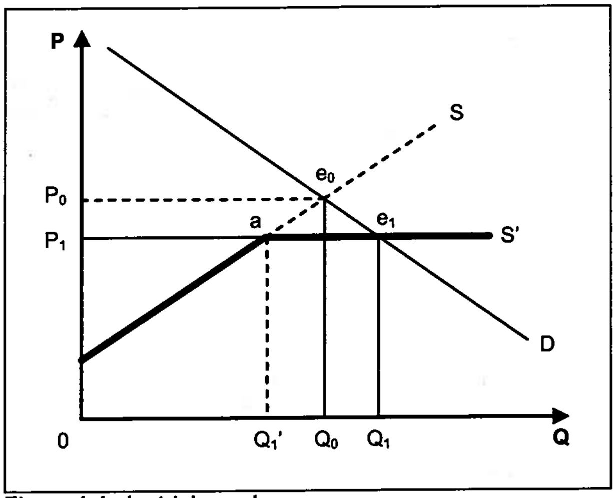

Figure 1. Industrial wood.

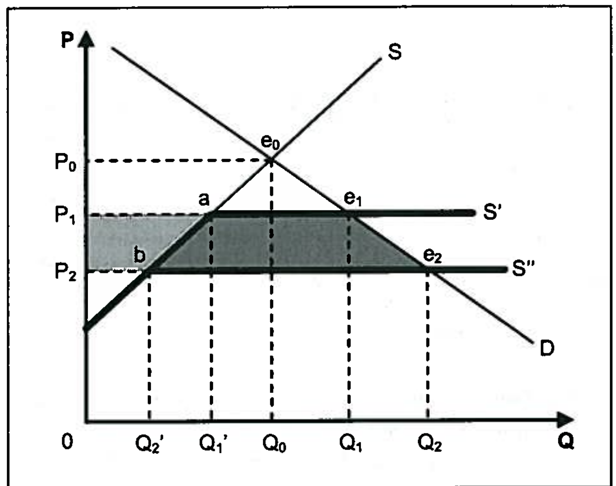

Figure 2. Industrial wood: biotechnology welfare.

eration improvement in the desired characteristic (e.g., yield). More sophisticated seed collection and deployment techniques, such as collecting seed from the best mothers, can result in an 11% increase in yield, whereas mass-controlled pollination techniques, which control for both male and female genes (full sibling), have increased yields up to 21%.

The Economics of Plantation Forests

Currently, most of the world's industrial wood is still drawn from natural forests in what is essentially a foraging operation. Plantation forests, in addition to natural forests, provide another "wood basket" with which to meet society's industrial wood requirements. Hence, plantation forests have served to supplement the global wood supply. Furthermore, analysis suggests that a high rate of financial return can be achieved by industrial plantations in many regions of the world; this has been reflected in the high rates at which plantation forests are being established. While some have challenged the economics of planted forests, the experience of the last several decades indicates that many private firms are willing to make substantial investments in planting forests for industrial wood purposes even while waiting decades before harvests can occur.

Figure 1 illustrates the economic effects associated with the lowering of cost provided by planted forests. In the absence of forest plantation,s the volume of industrial wood harvested in a period is determined by the intersection of supply S and demand D at e_0. In this situation, price is P_0 and the quantity harvested is Q_0. The introduction of relatively low-cost plantation forestry is represented by the line segment aS. At price P_1 plantations provide a cheaper source of industrial wood than do natural forests. This new source of timber results in a new equilibrium e_1 with a lower price P_1 and a higher harvest volume Q_1. Notice, however, that the volume harvested from natural forests is reduced from Q_0 to Q_1. This reflects the fact that the low-cost plantation wood is displacing wood from natural forests. The effects of biotechnology are to further reduce the costs of production, thereby shifting down even further the aS portion of the supply curve (not shown in Figure 1). The horizontal portion of the curve is what is referred to in the natural resource literature as "back stop" technology, in that the new technology—intensively managed plantations—will set a ceiling price.

Note that while in the transition, both natural forests and plantations provide industrial wood. The model suggests (and the experience of recent decades confirms) that the global transition has been a relative shift away from industrial wood from natural forests toward increased output from planted forests.

Although planted forests have increased the returns to forest investments, technology innovations (including cost-reducing transgenic trees) offer the potential for additional social benefits. Studies have estimated that large potential cost savings are likely to be associated with various transgenic innovations (see Context Consulting, as cited in Sedjo, 2001).

Figure 2 identifies the welfare implications from the introduction of cost-reducing biotechnology in planted forests. The introduction of transgenics further reduces costs, thereby shifting the supply curve down to S. The result is that planted forests gain an additional competitive advantage over natural forests. Plantation harvests rise while natural forest harvests fall. Consumers again benefit from the increase in consumer surplus equal to the area $P_2e_2e_1P_1$. Producers harvesting from natural forests suffer additional losses as their producer surplus is further reduced by P_1P_2ba. Net economic welfare benefits that accrue to society from tree biotechnology are represented by the area of the trapezoid bae_1e_2. In addition, one might argue that there are additional social welfare effects, in that the nonmarket outputs of the natural forest (e.g., wildlife, biodiversity) are maintained, rather than lost, as they might be if greater amounts of natural forest were harvested.

The US Regulatory Framework

The Regulation of Transgenic Trees

Three main agencies are involved in regulating transgenics: The Department of Agricultural, Animal and Plant Health Inspection Service (APHIS), the Food and Drug Administration (FDA) of the Department of Agriculture, and the Environmental Protection Agency (EPA). The FDA is involved with food safety, and the EPA is involved with pesticides and toxics (via the Toxic Substances Control Act and the Federal Insecticide, Fungicide and Rodenticide Act) as well as overall environmental safety. The three agencies are directed to coordinate their efforts via the Framework for the Regulation of Biotechnology (1986).

This paper looks primarily at APHIS, which gets much of its authority through the Plant Protection Act, the Federal Plant Pest Act, and the Federal Plant Quarantine Act. As the regulatory structure suggests, the primary reason for regulation of transgenics is the concern that there may be health, safety or environmental risks. The problem areas for trees are largely environmental (e.g., see Mullin & Bertrand, 1998). Do the introduction of transgenics introduce new risks of environmental damages? The Federal Plant Pest Act clearly reflects concerns about the extent to which transgenics could become weed pests.

More broadly, there are concerns that damages due to gene flow could occur or that transgenics could in other ways disrupt the environment (DiFazio, Leonardi, Cheng, & Strass, 1999). Dan Botkin (2001) has likened a transgenic to the introduction of an exotic—some of which have become invasive. Many ecologists have argued, however, that the risks of a transgenic are generally lower (or at least more predictable) than those of an exotic, because the transgenic plant has only a couple of introduced genes, and the general expression of these are known; therefore, the expression or any problems associated with it should be easier to identify.

In any event, it is primarily the concern for environmental risks that is the reason for the regulation of transgenic trees. Trees are different than many plants due to their long life and delayed flowering, which complicates their assessment and, in general, the entire regulatory problem. Delayed flowering generally makes it more difficult to determine the impacts of introduced genes over generations. Although certain tissue cultural approaches may be helpful in reducing the intergenerational delays, the regulatory problem is likely to persist.

The basic approach is as follows: Transgenic plants are automatically defined as a regulated article. The regulatory process is designed to assess a plant to determine if it is harmful. If it is found to be nonharmful, it can be deregulated.

There are three steps in the regulatory process for transgenics: (a) A permit must be obtained to import, to transport interstate, or to release transgenics into the environment; (b) field testing requires notification of APHIS; and (c) a petition must be submitted for the determination of nonregulated status. Upon receipt of the petition, APHIS makes a determination of whether to deregulate. Deregulation is based on assessment of the results of field testing, statistical analyses, literature review, and so forth. AHPIS reviews about 1,000 applications for field testing of transgenics each year. Only about 59 transgenics, representing 13 species, have been deregulated over the past 15 years. Examples of deregulated articles include salt- and drought-tolerant Bermuda grass, maize-expressing proteins with pharmaceutical applications, virus-resistant squash, soybean with altered oil profile, Bt corn, and herbicide-tolerant and insect-resistant cotton.

Deregulation Performance of Trees in the US

There are three types of trees that APHIS might consider deregulating: orchard, ornamental, and wood trees. Table 4 illustrates the history of field tests of wood trees in the United States. A total of 90 wood tree field tests were undertaken with four types of trees between 1987 and 2001, with poplar being involved in over half of the trials. Wood trees were involved in only 1.2% of the total number of field tests over that period. Most of those occurred in the latest reported period (1997–2001).

Table 5 provides some information about the length of the time period and the field size of the trials. The average time was between one and almost seven years

Table 4. Number of field tests for timber crops by date range.

	Poplar	Pine	Walnut	Cottonwood	Total	Total APHIS-approved crops	% timber trees to total crops
1987–1991	1	0	2	0	3	181	1.7
1992–1996	3	0	2	0	5	2,354	0.2
1997–2001	52	15	8	7	82	4,804	1.7
Total	56	15	12	7	90	7,339	1.2

Note. Data from Information Systems for Biotechnology (2004).

Table 5. Average field test length and size of APHIS-approved trials of GM poplar, pine, cottonwood, and walnut, 1987 to July 2002.

Tree	APHIS-approved tests	Average field test length	Average field test size (acres)
Poplars	65	1 year, 2 months	1.50
Pines	17	6 years, 8 months	0.25
Walnut	12	4 years, 7 months	1.90
Cottonwoods	7	3 years, 9 months	2.60

Note. Data from Information Systems for Biotechnology (2004).

on fields covering an average of 0.25–2.6 acres (all averaged about one hectare or less). Trees make up only a small portion of the plants tested, and about 57% of the trees are timber trees. However, the number of trees tested has increased dramatically in recent years (as has the total number of plants of all types).

The United States is not the only country involved in field trials. Although an estimated 61% of worldwide tree trials are in the United States, other countries undertaking field trials include Australia, Canada, Chile, France, Italy, Japan, New Zealand, and South Africa.

Despite increasing field testing in recent years, only one tree has been deregulated by APHIS—the papaya. This tree was experiencing severe disease problems in Hawaii. A genetic modification was developed to address the disease; the transgenic papaya was deregulated and is now in widespread use in Hawaii. Despite this success, no other trees seem ready for imminent deregulation.

Some Deregulatory Issues

An important issue in trees (as well as in other plants) involves the conflict of *process* with *product*. As currently interpreted, regulation in the United States is associated with the transgenic process, not with an appraisal of the particular risk associated with a new plant, whether traditionally bred or transgenic. A plant that involves the insertion of a gene using a nonsexual approach is defined as a transgenic and is automatically subject to regulation. A protocol is then applied whereby the transgenic plant is controlled, and a series of tests and procedures are required to determine whether the plant can be deregulated.

Some biologists have argued that regulation would better be applied on the basis of the product produced, whether it is the product of traditional breeding, not now subject to regulation, or the production of a transgenic procedure. In fact, the US decision criteria are that the *product* have "no significant or unreasonable adverse risks." However, this criteria is applied only to transgenic plants.

The biologists' argument, which appears to be consistent with the regulatory change, is that the process does not lead to inherently more risky products. Rather, it is the features of the changes and the attributes, whether generated by traditional or transgenic approaches, which could provide a social or environmental risk. Thus, the risks are in the attributes of the products; it is the products with these attributes that ought to be regulated.

Countries vary in their application of regulations. China has a scale ranging from no, low, medium, to high risk. After a preliminary appraisal, products are given a risk rating; those in the no to low range are automatically deregulated. By contrast, other countries, including Canada, the European Union (EU), and the United States, automatically regulate all transgenics and require a formal deregulation for all. The US and Canadian criteria each allow for the presence of some risk, whereas that of the EU does not allow the plant to pose any additional or higher risks. Thus, the EU calls for a zero-risk criteria.

Summary and Conclusions

This paper discusses some issues regarding the setting, potential, economic returns, and regulatory system related to transgenic trees. Due to the widespread establishment of plantation forests, tree breeding and tree biotechnology offer great economic potential. Today, tree genetic modification is in its infancy, but research and development are in the process of adding desired traits that will increase value. A number of the more promising tree biotech innovations are discussed; some of the economics of tree biotechnology are examined in this paper. The economics suggest that social benefits could be obtained from lower-cost wood production that might be forthcoming from transgenic trees. This paper also examines the US regulatory framework for transgenic plants generally and its application to trees. Although the number of innovations being field tested has been increasing rapidly, thus far only one tree has been deregulated—and that is a fruit tree. Thus, the potential of transgenic forestry to produce wood has not yet cleared the regulatory hurdle required for its commercial application.

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