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Intellectual Property Rights, Genetic Use Restriction Technologies (GURTs), and Strategic Behavior

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Agriculture is important to the economy and welfare of both developed and developing countries. Agriculture provides foods and raw materials, and it is a major economic sector in many developing countries. For years researchers all over the world have been trying to discover agricultural technologies that will increase crop yields with minimal environmental impacts and benefit both farmers and consumers. Genetic modification (GM) technologies have received increasingly more attention from both the research sector and the public. They remain a controversial issue in many countries due to concerns related to biosafety, environment, income distribution, international equity, conservation of genetic resources, and national security (e.g. bioterrorism, international dependency). However, genetic modification is not really a new idea in plant breeding. Plant breeders have been transferring and/or stacking genes by making crosses between parents which each have a desired trait and then identifying offspring that have both of these desired traits. Gene modification or genetic transformation using modern biotech can provide a faster and more dependable method of producing a plant with specific desirable traits. It might also have effects on the environment and on other conventional producers that might be undesirable or costly.

The world has seen a rapid growth in GM crops planted both in developed and developing countries. Cost, yield and risk considerations have provided strong incentives to further adopt GM technology (Kalaitzandonakes 1999). In 1996 GM crops were first introduced for commercial production on 4.2 million acres in 6 countries. By 2005, GM production grew to a total of 222 million acres in 21 countries on six continents (James 2005). The US is the largest adopter with 122.8 million acres, followed by Argentina, Brazil, Canada, and China. These five countries contain about 95% of the global GM cropland (James 2005). According to Stephanie Childs of the Grocery Manufacturers of America, it is estimated that about 75% of all processed foods in the U.S. today contain some GM ingredients (Johnson in ABC News, March 23, 2005).

Protection of intellectual property has been an important element in the development and commercialization of agricultural biotechnology. Starting in 1970, the U.S. government has recognized plant breeders' rights to sexually propagated crop varieties via issue of plant variety protection certificates (PVPCs) and plant patents have been available for many clonally propagated varieties since 1930s. More recently, patent protection has been expanded to sexually propagated plant varieties, spurring research and development (R&D) in transgenic crops. Biotechnology and intellectual property protection are mutually reinforcing in strengthening privatization of innovations in this field. Biotech research makes it possible to enable the enforcement of the intellectual property rights (IPRs) in agriculture. The IPRs, in turn, make it possible to capture more private value from biotech research by giving ownership of technology to the innovator. In the late 1990s US agri-business has become the second most profitable industry next to pharmaceuticals, and the profitability has been driven mainly by the dramatic development in biotechnology and the IPRs (Magdoff et al., 2000). Under the Bayh-Dole Act, universities and other public and non-profit institutions can license or sell their rights to their research outputs, and they share the proceeds with the researchers.

Genetic Use Restriction Technologies (GURTs)

Events since the 1980s have affected the type of research being carried out, and who does the research. Most of the research efforts so far have been focused on staple crops including cotton, corn and soybean in the developed countries. Non-staple crops, also called "orphan crops", have received relatively insignificant research investment. The private seed sector did not invest in orphan crop research because the profits are not sufficient to cover the cost of research. The private seed sector also hesitates to spend research investments on crop varieties that fit the needs of developing countries because of lack of effective enforcement of IPRs and/or the market has small financial value.

Despite the expanding scope of legal protection, however, the biotechnology sector also engaged in developing technologies to facilitate the appropriation of returns to innovation. These technologies, collectively dubbed Genetic Use Restriction Technologies (GURTs), enable the control of plant reproduction and inducible traits. There are two kinds: variety-restriction GURTs (V-GURTs) render the subsequent generation sterile, while trait-restrictive GURTs (T-GURTs) ensure that the enhanced trait can be turned "on" and "off" by certain conditions such as chemical application, environmental factor like heat (Jefferson etc., 1999). Hybrid technology shares some degree of use restriction with GURTs, where the second generation hybrid seeds do not perform as well as the first generation. However, hybrids might be infeasible, or ineffective for many self-fertilizing crops such as rice, wheat, soybean, cotton and horticultural crops. These crops are likely to be the target application of V-GURTs. T-GURTs may in principle be applied to virtually all crops to protect the enhanced trait in commercial varieties. Table 1 lists some potential targets of GURT applications (adopted from Visser et al. 2001).

Table 1. Potential Targets Of GURT Applications

Sector	Trait examples	Remarks
Wheat	Nutrient quality; taste; yield; disease resistance; drought avoidance; cold tolerance	Staple crops; increased R&D expected
Rice		Staple crop; increased R&D expected
Maize		Staple/specialty products; gene flow containment desirable
Soybean	Nutrient quality; feed quality	
Cotton	Agronomic traits; color	Increased R&D expected
Oilcrops	Fatty acid composition	Sunflower, olive, oil palm; Canola: gene flow containment
Horticultural crops	Quality traits	V-GURTs for non-hybrids
Plantation crops	Agronomic traits	Coffee, banana
Cattle	Meat quality; feed conversion efficiency	Specialty products (pharmaceuticals)
Fish and other aquatic species	Environmental concerns; yield; low temperature tolerance; disease resistance	Salmonids, carp, tilapia, crustaceans, molluscs

Source: Visser et al. (2001).

V-GURTs, also known as "Terminator" technology, have received widespread condemnation from the global society since the first recognized[1] terminator technology patents issued in 1998: US 5,723,765, jointly held by USDA and Delta & Pine Land

[1] It has been widely cited that the terminator technology patent issued to USDA/D&PL in March 1998 (filed in June 1995) is the "first" terminator technology. However, in ETC (2003), we found technology application (WO9403619) filed by Zeneca (Syngenta) was published by WIPO in February 1994 (filed in 1992). We found details of this technology in CAMBIA website. This technology contains "a gene switch which is inducible by external application of a chemical inducer and which controls expression of a gene product which affects expression of a second gene in the genome". Syngenta received European patent for this technology in 2002, and filed for the U.S. patent in 2005. In terms of publicity and world recognition, the USDA/D&PL one is the "first" GURTs technology.

(D&PL) Seed Company. In brief, the USDA/D&PL technology involves inserting three transgenes (toxin gene, site-specific recombinase gene, and recombinase repressor gene) into the plant DNA. The genes are connected so that (a) the repressor gene prevents the recombinase gene from functioning, (b) the recombinase gene, if it functions, allows the toxin gene to activate, and (c) the toxin gene produces a toxin that kills the embryo in the seed, so that the seed cannot germinate. The seed producer can control the system by spraying the first generation seed with a regulator. The regulator then inactivates the repressor gene. Since the repressor gene doesn't function, the recombinase gene is allowed to do its job, as in step (b) above. If the seed producer wishes to protect the intellectual property embedded in the seed, he sprays the seed with the regulator before delivery to the farmer.

At least three V-GURT strategies can be distinguished (FAO 2001). In strategy 1, the seed is fertile by default. The activator is used to induce a disrupter gene which results in sterility in next generation. The breeder treats the seeds with a chemical inducer when sold, thus the second-generation seed is fit for consumption but infertile. USDA/D&PL technology mentioned above follows strategy 1. In strategy 2, the seed is infertile by default; the breeder applies a chemical in all generations to inactivate the disrupter gene that causes the sterility, but not before selling the seeds. Strategy 3 focuses on crops reproduced vegetatively such as roots and tubers. Growth can be prevented during storage and it helps to extend shelf life. In this case, the blocking gene is expressed by default until being suppressed by application of a chemical.

Compared to V-GURTs, there seems to be less public outrage against T-GURTs. There are two possible ways in which T-GURTs can be designed (FAO 2001). In case 1, a chain of genes, similar to the one described above for V-GURTs, is constructed. The system can be programmed so that the toxin gene deletes a "trait" gene instead of killing the embryo. Thus, if the seed is sprayed with regulator before delivery to the farmer, the first generation seed will produce the trait embodied in the trait gene, but the second generation will not[2]. In case 2, the farmer activates the trait by applying an "activator" compound to the plant or seed. The system can be designed so that subsequent generations of the seed will contain the trait gene, but in an inactive state. Thus, use of the trait in a given year requires the farmer to purchase and apply the activator in that year[3]. In addition, USDA (2001) suggests a T-GURT that can be activated by the farmer's spraying a "standing crop" with the activator. It is not clear if such a technology is feasible, or even if it were feasible, whether the timing of application of the activator would be flexible. If the timing of application were flexible, this would confer option value upon the T-GURT-protected trait.

Global reaction and GURTs today

Ever since the V-GURTs came into public attention in 1998, there has been a global outcry to condemn this set of technologies in many non-government organizations (NGOs) and governments in the developing and developed world. The United Nations

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[2] According to Jefferson et al. (1999), Zeneca has filed a patent for a system such as described here.
[3] Under this system, the farmer may save seed for planting in subsequent years. This implies that technology use agreements need not be signed. Moreover, the activator must be a patented compound, since it is from sales of the activator that the manufacturer recoups his investment.

Conference on Environment and Development (UNCED) in April 1999, the UN Food and Agricultural Organization (FAO) in 1998, and the Rockefeller Foundation in June 1999, have all stated that they are against terminator seeds. The Consultative Group on International Agricultural Research (CGIAR) recommended in 1998 that its 16 research institutes avoid terminator technology in their crop-improvement programs. Panama, India, Ghana and Uganda all said that terminator technology should not be developed. The U.K. government said that they would not allow developing, testing or using breeding material which was designed to prevent seed germination. Debates over GURTs happened at the Fifth Conference of the Parties (COP5) to the UN Convention on Biological Diversity (CBD) held in Nairobi in June 2000. The UN recommended that products with such technologies should not be approved for field testing until sufficient scientific assessments had been carried out. On the other hand, there does not seem to be public condemnation against T-GURTs even though GURTs objectors argue that both T-GURTs and V-GURTs share similar negative characteristics. For example, the CGIAR remains silent on T-GURTs while rejecting terminator technology. Many of the public statements made by those NGOs mentioned above are specifically targeted against V-GURTs, but do not mention T-GURTs.

Since the first planting of a GM crop, the agricultural biotechnology industry has experienced substantial consolidation and transformation into biotechnology giants which integrate local seed companies, plant-breeding and biotech companies. By 2000, four companies account for virtually the entire global GM market: Syngenta, Monsanto, Aventis, and DuPont. Along with the public outrage over V-GURTs, major biotech companies have announced that they will not develop or commercialize the Terminator technology. In 1999 Zeneca (now Syngenta[4]) Agrochemical said that they were not developing and would not develop any system that stops farmers growing second generation seed. Novartis (now Syngenta) said in February 2000 that they had a long standing policy not to use GURTs to prevent seed germination. Monsanto's CEO, Robert Shapiro, claimed in 1999 that they were "not to commercialize gene protection system that renders seed sterile". On the other hand, D&PL made a straight claim in 2000 that they will continue on commercializing the technology protection system and never back off (Collins 2000). Moreover, for those companies who said no to V-GURTs, they have left themselves the option to develop T-GURTs.

The patent statistics tell another story regarding what these companies truly believe (table 2). R&D concerning V-GURTs and T-GURTs has continued since the public announcements were made, and no players actually withdrew any GURTs type patents or patent applications[5]. The U.S. Department of Agriculture has refused to withdraw its patent claim on the original terminator technology, and USDA/D&PL have received two new terminator patents and has been testing the technology in laboratory conditions. Experimental terminator tobacco plants have been grown at the USDA lab in Lubbock, Texas. ETC[6] found that 43 patents on trait specifics T-GURTs were filed till 2000 (RAFI 2000). Table 2 lists some V-GURTs and T-GURTs type patents issued

[4] The UK-based Zeneca Group PLC. merged with Astra Ab. from Sweden in 1999 to form AstraZeneca. In October 2000 AstraZeneca and Novartis merged their agribusiness interests to become Syngenta. Novartis, was formed when Swiss agrochemical/pharmaceutical companies Ciba-Geigy and Sandoz merged in 1996.
[5] ExSeed (now BASF) withdrew its patent application (WO9907211) from European Patent Office in 2004, but not from some other national phases including Australia, Canada, China, and New Zealand.
[6]The ETC Group - Erosion, Technology and Concentration Group, is formerly known as the Rural Advancement Foundation International (RAFI).

to or filed by those major biotechnology companies and institutes in recent years. The most recent GURTs type patent we found was published on September 6, 2005, owned by Syngenta (US6,939,711). Syngenta is the dominant player in developing GURTs type technology. It likely owns more than half of the GURTs patents issued so far.

Table 2. Selective V-GURTs And T-GURTs Type Patents Issued/Applied By Major Biotech Companies/Institutes

Company/ Institution	Patent (or application) number	Date issued/ filed	Remarks[a]
BASF (ExSeed/ Iowa State Univeristy)	WO9907211 Control germination using inducible	02/18/99	National phase entry to AU, CA, CN, NZ in 2000; withdrawn from EPO in 2004
Cornell Research Foundation	US 5,859,328 (WO9425613) female sterility in plants	01/12/99	PCT published in 1994; phase entry to AU; no phase entry to CA, EU
Delta&Pine Land/USDA	US 5,723,765 (WO9604393) Control plant gene expression	03/03/98	PCT published in 1996; phase entry to AT, AU, BR, CA, CN, EU, JP, TR, ZA in 1997 – 1998; AU patent granted in 1998; CN patent granted in 2003; HK patent granted in 2004; done with EPO in 2005
Delta&Pine Land/USDA	US 5,925,808 Control plant gene expression	07/20/99	
Delta&Pine Land/USDA	US 5,977,441 Control plant gene expression	11/02/99	
DuPont (Pioneer Hi-Bred)	US 5,859,341 Mediate fertility, method of use	01/12/99	Filed in 1995; continuation of patent US5,478,369
DuPont (Pioneer Hi-Bred)	US 6,297,426 Mediate female fertility in plants	10/02/01	Filed in 1998; continuation of patent US5,859,341
DuPont (Pioneer Hi-Bred)	US 6,265,640 Mediate fertility, method of use	07/24/01	Filed in 1998; continuation of patents US5,850,014 and US5,478,369
Monsanto	WO9744465 Control seed germination	11/27/97	No national phase entry data
Syngenta (Zeneca)	WO9403619A2 and A3 Improved plant germplasm	02/17/94	Filed in 1992; done with EPO in 2002; filed in US in 2005 (phase entry in 1995)
Syngenta (Zeneca)	US6,228,643 (WO9735983A2)	05/08/01	PCT published in1997; done with EPO in 2005;

	Promoter, containment of plant germination		lapsed in SE, GR, DK, PT in 2006; national phase entry to CA, KR, NZ in 1998
Syngenta (Zeneca)	WO9738106A1 Gene promoter sequence from banana	10/16/97	No phase entry to EU, Japan, CA
Syngenta (Zeneca)	US 5,808,034 Plant gene construct comprising male flower specific promoters	09/15/98	Filed in 1994
Syngenta (Zeneca)	US 6,172,279 Plant gene construct encoding a protein disrupting viable pollen	01/09/01	Continuation of patent US5,808,034
Syngenta (AstraZeneca)	US 6,700,039 (WO9906578) Controlling sprouting	03/02/04	PCT published in 1999; phase entry to AU, CA and CN in 1999 -2000
Syngenta (AstraZeneca)	WO9929881 Increasing yield, controlling flowering behavior	06/17/99	Filed in EPO, Japan, and phase entry to USA, AU, CA in 2000
Syngenta (AstraZeneca)	US6,683,230 (WO9942598) Hybrid seed production	01/27/04	PCT published in 1999; phase entry to AU, CA, CN, IL, KR in 1999; CN patent granted in 2005
Syngenta (AstraZeneca)	WO0009704 Gene switch	02/24/00	Phase entry to AU, CA in 2001
Syngenta (AstraZeneca)	WO0009708 Disrupt cell function	02/24/00	Phase entry to AU, CA, CN, IL in 2001
Syngenta (Novartis)	US5,880,333 Control gene expression	03/09/99	Done with EPO in 2005; lapse in SE in 2006
Syngenta (Novartis)	US6,018,104 Nucleic acid promoter	01/25/00	Filed in 1995
Syngenta (Novartis)	US6,018,105 (WO9732028) Promoters of plant protoporhyringen oxidase genes	01/25/00	PCT published in 1997; AU patent granted in 2000; withdrawn from EPO in 2004; no entry to CA
Syngenta (Novartis)	US6,031,153 (WO9829537) Method of protecting plant	02/29/00	Continuation of patent US5,780,469; phase entry to JP in 1999, EPO 1998; AU patent granted in 2000; RU patent granted in 2004; CN, HU patents granted in 2005; PL patent granted in 2006
Syngenta (Novartis)	US2002133846 Method of protecting plant	Filing published	Divisional continuation of patent US6,031,153

		09/19/02	
Syngenta (Novartis)	US6,057,490 Method for selecting disease resistant mutant plants	05/02/00	Filed in Dec. 1998; continuation-in-part of patent US5,792,904
Syngenta (Novartis)	US6,091,004 Signal transduction cascade leading to acquired resistance	07/18/00	Filed in 1997;
Syngenta (Novartis)	US2002152499 Signal transduction cascade leading to acquired resistance	Filing published 10/17/02	Continuation of patent US6,091,004
Syngenta (Novartis)	US6,147,282 Control the fertility of a plant	11/14/00	Filed in 1999; divisional continuation of patent US5,880,333
Syngenta (Novartis)	US6,107,544 Method for breeding disease resistance into plants	08/22/00	Filed in 1997; continuation-in-part of patent US5,792,904
Syngenta (Zeneca)	US6,362,394 (WO9713864) Control gene expression	03/26/02	PCT published in 1997; phase entry to CA, CN, JP in 1998; AU patent granted in 1999; deemed to be withdrawn from EPO in 2004
Syngenta	US6,610,828 Gene switch receptor protein	08/26/03	Filed in 2000; divisional continuation of patent US6,379,945
Syngenta	US6,605,754 (WO9321334) Chemically inducible gene expression	08/12/03	PCT published in 1993; phase entry to the US in 1998; done with EPO in 2001
Syngenta	US6,939,711 (WO9627673) Control of plant gene expression	09/06/05	PCT published in 1996; continuation of patent US6,147,282; phase entry to CA, JP in 1997; AU patent granted in 1999; done with EPO in 2005; lapse in SE in 2005
? (Jenkins &Wilson, PA, a patent firm)	US2004058369 Method for controlling gene expression	Filing published 03/25/04	Syngenta's inventor?

a: Capital letters are country abbreviations.
Sources: ETC group (2003), Warwick (2000),
USPTO database (http://www.uspto.gov/patft/index.html),
WIPO database (http://www.wipo.int/tools/en/databases.jsp),
CAMBIA patent database (http://www.bios.net/daisy/bios/50).

The force of commitment against V-GURTs is at present not clear. For example, Zeneca's U.S. joint venture, ExSeed Genetics, applied patents through WIPO (WO 9907211) on a terminator type technology, and the application was published on February 18th, 1999 (table 2), but the research director of Zeneca told the public one week later that Zeneca was not developing any system that would stop farmers from growing second generation seed. D&PL's VP of Technology Transfer, Harry Collins, and Monsanto's VP of Seed Strategy and Seed Quality Division, Roger Krueger, claimed in 2003 that no GURTs have been approved for release in field testing and commercialization (Collins and Kruger 2003). However, at least one T-GURT has been tested in the UK. Potatoes with an alcohol-sensitive switch mechanism to control when the potato sprouts was field-tested at Zeneca's Jealotts Hill research station in Berkshire in 1999 and 2000 (Warwick 2000).

The potential impacts of GURTs

Proponents of and objectors to GURTs both hold strong but speculative opinions on the potential impacts of this new set of technologies. The potential impacts of GURTs and related policy issues have been discussed in various forums including the FAO Committee on Agricultural, the Conference of Parties to the CBD, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the UN Environment Programme (UNEP), and in other non-government organizations and research bodies. We will discuss views on the potential benefits first, and then address the objectors' claims.

Potential benefits of GURTs

Most speculation about the benefits of developing GURTs concentrates on three aspects: use restriction to ensure an adequate return to research; agricultural productivity contributions; and biodiversity and Green Gene Defense (FAO 2001). The International Seed Federation (ISF) believes that GURTs have the potential to benefit farmers and others in different economic and geographical areas, because the use restriction gives greater incentive to conduct breeding research in crop species and geographies which have received little or no research attention in the past due to the lack of sufficient return to research (Collins and Kruger 2003). The logic is that because of an increased return to research, there shall be an increase in market competition with more entries to a market area and more new improved varieties being supplied. Therefore, GURTs will result in increased choices to farmers. In terms of agricultural productivity contribution, there may be production advantages of restricting trait expression in a specific phase of plant development. T-GURTs could also be used to prevent pre-harvest sprouting, or to extend shelf life of the agricultural products, or to help inbreeding hybrids by switching from sterile to fertile and back.

In terms of biodiversity, as mentioned above, Collins and Krueger (2003) argue that increased competition among seed companies and the willingness to introduce varieties result in many new and diverse varieties for local farmers in a region, therefore more diversity than in the past. Another appealing argument is that GURTs provide a Green Gene Defense system. The seed industry argues that GURTs offers a built-in safety feature for GM plants because if genes from a V-GURT crop cross-pollinate with related plants in the neighboring area, the seed produced from the pollination will be sterile, and T-GURTs trait may be contained even if unplanned out-crossing occurs because inducers will not be applied in the neighboring plants anyway.

In 2002, the UK government's Advisory Committee on Releases into the Environment described GURTs as promising in avoiding gene escape to wild relatives or landraces. The New Zealand Royal Commission on GM recommended that V-GURTs receive funding priority from government grants (Hanley and Elborough 2002). It seems that GURTs could stay because GM crops are here to stay. If the Green Gene Defense argument is valid, then GURTs may be one of the strategies needed to act responsibly while benefiting from biotechnology. However, others argue that the sterile seeds in neighboring crops could reduce their yield in subsequent years, which is a negative externality to the neighboring farmers. The T-GURTs traits may be unintentionally induced by related substances or by naturally occurring trigger events even though no proprietary activators are applied. Therefore, it is doubtful how effectively the defense scheme provided by GURTs will work.

There are other potential benefits related to GURTs that are often not pointed out. Licensing of traits from the private sector, where the private provider controls the activators of the genetic traits, could constitute an important reduction in costs of private-public technology transfer. Much of the transaction costs in technology transfer are related to asymmetric information on the value of traits incorporated in the final product. Uncertainty and asymmetric information on the performance of a trait increase the difficulty in negotiating a licensing/technology transfer contract from the private sector to the public sector, which in turn increase the costs substantially. If the private sector controls the activators of the genetic trait if the traits are independent, the asymmetric information problem no longer exists.

Using GURTS, farmers can switch from "traits as self-insurance," purchased in a package *ex ante*, to "traits" as self-protection (or mitigation of damage) *ex post*, which may affect the transactions cost, productive efficiency, feasibility of public cultivar development, and trait demand. We may consider use of GURTS, so that the seed producer, possibly public or nonprofit, markets its seed as a vector of trait options. To exercise the latter, the farmer pays the relevant innovator for use of the "activator" which switches on the trait.

The literature on commodity bundling suggest that allowing mixed bundling may be welfare improving for both consumers and producers in general (Adams and Yellen 1976). If T-GURTs make it possible that farmers could choose to activate any subset of the trait options (mixed bundling), then it is likely to be welfare improving. For example, before Monsanto introduced the seed with the stacked system of its *Bt* and Roundup Ready (RR) genes, GM adopted farmers can only choose between planting the *Bt* seeds and spraying the herbicide before planting, or planting the RR seeds and applying the pesticide manually later on, if necessary. There are farmers who suffer heavy infestations in both regards, and they benefit a lot from the introduction of the stacked system of both *Bt* and RR. On the other hand, if Monsanto supplies only the stacked system, farmers who have heavy pest infestation but light weed infestation, and farmers who have light pest infestation but heavy weed infestation would have to pay for a trait that they might not prefer, which may drive them away from buying the stacked seed at all. By supplying the *Bt* seeds, the RR seeds, and the *Bt*/RR stacked seeds, Monsanto are using a mixed bundling strategy, which should be welfare improving, although some subset of individual farmers will be worse off. Moreover, if using T-GURTs in production, Monsanto may supply the stacked seeds, and leave the farmers to choose which activators they would like to use when they are buying the seeds. This may constitute a sizable cost reduction in producing and marketing one type of seed instead of three types of seed. If a sufficient part of the cost reduction is passed to the farmers, then both producer and farmers could benefit from the new technology.

Moreover, firms with market power could use bundling or not to bundle to constitute strategies to leverage market power (Whinston 1990, Nalebuff 2004, Shi 2005). Shi (2005) show that the incumbent firm's commitment not to bundle could deter the potential entrant firm entering the market, and how the strategic use of commitment not to bundle could be used in the agricultural biotechnology industry. However, these analyses do not consider the possible incorporation of GURTs into the seed. With T-GURTs, commitment to bundle or not to bundle may be made through the supplying of activators to the farmers. If the producer does not provide the farmers with the flexibility of choosing any subset of activators they prefer, then it is equivalent to a bundling strategy (the producer bundles, and farmers decide to buy or not). If the producer licenses the activator to a chemical producer, then the producer should be able to construct the contract as a credible commitment not to bundle, because farmers could buy the activators they want from the chemical producer. Potential entrants to the market of any subset of the traits may be deterred effectively, because the incumbent seed producer virtually provides all the options to farmers. If there are a total of 5 traits included in the seed, then farmers' self selection makes it equivalent to $C_5^1 + C_5^2 + C_5^3 + C_5^4 + C_5^5 = 31$ different types of seed. Therefore, at least in theory, the incumbent could effectively deter entry into all the 31 "markets".

Another application of GURTs that has not attracted much attention is the possible role that GURTs can play in the refuge mechanism. Pesticide-resistance buildup is a serious problem in all kinds of farming system where pesticide, either conventional or via GM, is applied to control the pest infestation. Right now the most commonly used practice to handle this problem is the so-called refuge design, i.e. retaining an area in the cropland where no insecticide will be sprayed on the crops in that area. With GURTs, farmers or government could choose to spray the activator or suppressor related to the specific insecticide trait in any specific area any time in the season as needed.

Potential risks of GURTs

Objectors to GURTs condemn GURTs, especially V-GURTs, as nonethical, dangerous, and anti-farmers' rights. They argue that both V-GURTs and T-GURTs share similar negative characteristics: T-GURTs tie plants to a chemical activator while V-GURTs kill seed. In the extreme case, farmers may not be able to buy seeds with a fully operational system.[7] The concerns relate to three issues: the potential abuse of monopoly power;

[7] It is said that Sygenta's patent (US6,091,004) makes it possible to use T-GURT to disable the crops' natural immune system (Warwick 2000).

food security and sovereignty, and biodiversity and biosecurity. A less commonly mentioned concern is the threat of a so-called GURTs weapon.

The first set of concerns is that GURTs give a much stronger monopoly than patents do. The problem is that unlike patents, there is no expiration date of GURTs protection, and there is no exemption for plant breeders. The Crucible Group (including the International Plant Genetic Resources Institute and the Dag Hammarskjold Foundation) said that "… a patent is a time-limited, legal monopoly granted by a government in exchange for societal benefits. In the case of the Terminator, the biological monopoly is not time-limited, and is not necessarily approved by national governments." ((IDRC, IPGRI and Hammarskjold Foundation 2000). They believe that even though firms are still actively seeking patents protection over their GURTs methods, the expiration date on those GURTs patents will not affect the technology owner practicing his monopoly power.

Secondly, the key issue related to food security and sovereignty is that farmers cannot save seed with V-GURTs. Sterility is a threat to world food security to the extent that the food producing capacity of farmers is potentially restricted. Over three-quarters of the world's farmers use farm-saved seed as their primary seed source. Almost all the poor farmers in the developing world are following this pattern. These poor farmers may also go to informal seed markets (where they buy cheaper seeds) or to the consumption market for seeds, or they may use humanitarian food aid as seed. If GURTs enter these informal seed supply of those resource poor farmers, those farmers will risk disastrous crop loss.

If GURTs will reinforce the current trends of concentration in the private breeding sector so that seed supply is monopolized, then farmers may become dependent on GURT seed. They are unable to save seed for planting in the next season, and cannot purchase from another supplier (out of market). If the supplying monopolist encounters any crisis (similar to the contamination of flu-shot vaccine in the major supplier in 2004-2005, which reduced the supply by half in the U.S. that year), farmers may find themselves without seed to plant.

The third set of concerns with GURTs in place, is that farmers' inability to adapt crops to their unique farming environments because they can no longer take advantage of the improved germplasm provided in the commercial seeds. Therefore they cannot contribute to the enrichment of local genetic diversity. Farmers either adopt the GURTs seeds with the desired traits if the price is low enough, or no longer carry out the dynamic process of adapting the local crops, which had been used to help maintaining the local adaptive fitness and productivity. This impact is small in areas where farmers are already adopting commercial varieties which were developed for their farming system anyway. If GURTs induce the private breeding sector take over the local adaptive fitness and productivity activities, then the threat to reduce local biodiversity is also small. Otherwise, the loss of traditional, locally adapted varieties from farmers' breeding selection could have a significant impact on the long-term productivity of farming system in resource poor communities.

In responding to the Green Gene Defense argument, GURTs objectors argue that this defense claim itself has already admitted that there exists potential hazard of horizontal gene transfer, for which the biotech industries had assured the public that it would not be a problem when GM crops were first released into the field. There also exists the risk of gene-silencing, i.e. the intended mechanism such as sterility may fail to work, and some natural occurrence such as environmental factors may induce the T-GURTs trait transferred to the wild species. In either case, GURTs fail to function as the green gene defense mechanism.

Finally, a less mentioned threat is the so-called GURT weapons. GURTs may introduce a suicide sequence into plant species or animals through seeds, inputs that integrated with a recombinant vector, or some substances transmitting through air or water. It won't cause any harm until triggered. In fact the University of Texas has already experimented with its lethal GRIM system in mammalian cell cultures (for non-military purposes). The intruding country could apply whatever mechanism that activates the GURT, then even the existing of this threat could dramatically change the negotiation position among countries. So far GURT weapons remain theoretical at least to the public's knowledge, but they may be envisioned easily (RAFI 1999, Engdahl 2004).

In summary, GURTs opponents argue that the consequences of GURTs on farmers and consumers in developing countries and its potential negative impacts on environment and natural resource outweighed the benefits of protecting innovation and as green gene defense mechanism. To reach such a conclusion, one must accept the theoretical and empirical validity of the following assumptions:

1. Patent protection will not affect the monopoly position of the GURT method owner;

2. Once commercialized, the seed industry will incorporate V-GURTs into all their seed supplies;

We will discuss the validity of these assumptions in turn in the following sections.

Patenting will not affect the monopoly position of the GURT method owner?

This claim is naïve if not over simplified, but has often been used in accusations against GURTs in various situations. According to the definition given by the US PTO, a patent gives its owner "the right to **exclude** others from making, using, offering for sale, or selling the invention in the United States or importing the invention into the United States". A patent is often called a legal monopoly for a given time period (usually 20 years in the U.S.), because the patent owner has the right to sue for infringement.

How does the monopoly power given by GURTs work, if no IPRs are assigned? Both V-GURTs and T-GURTs require some type of inducer to activate or repress certain gene expression including seed germination capability and/or the enhanced trait. The GURT method owner's monopoly power relies on how well he can keep the inducer a secret if he fails to obtain a patent for his technology. If another firm figure out how to make the inducer via reverse-engineer or copying, then the GURT owner no longer has a monopoly position in the market. It may be true that farmers become dependent on the chemical to activate the enhance trait or fertility of the seed, but they are not subject to the control of a single firm. Competition may reduce the chemical price to such an extent that farmers are better off with this new technology. It may be argued that the GURT method owner could reap the benefits via the sale of seed rather than the sale of chemical.

Therefore, competition in the chemical market would not affect the GURT owner's monopoly rent. However, reverse engineering and independent innovation also exist for the GURT seeds, and production is possible given the activator is obtained. Without patent protection, it is likely that substitute GURT seeds will come into the market soon after the introduction of the initial GURT product.

A possible analogy might be the case of Monsanto's Roundup and Roundup Ready seeds. The patent on Monsanto's Roundup expired in 2000, but not on Roundup Ready seeds. The complementarities between Roundup and Roundup Ready used to tie the farmers who use Roundup Ready seeds with the herbicide Roundup. However, since the patent expiration in 2000, glyphosate (the basic ingredient in Monsanto's Roundup herbicide) has been produced by various generic producers. The foreseeable increased competition led to lowering price of Monsanto's Roundup products even before the expiration of the patent, dropping from about $44 a gallon in 1997 to $34 in 1999 to about $28 in 2001, and the most recent retailing price we found online is $23.5 to $25.5/gallon for Roundup Original Max on May 2nd, 2005 (http://www.xsag.com/Common/Guides/StartHere.asp). Monsanto announced in 2004 it is increasing the price of Roundup Ready soybeans in its Asgrow and Dekalb brands by $4 to $5/acre and Roundup Ready corn about $2/acre, and claim that the lowered list price of Roundup OriginalMax will make the total cost of buying RR soybean seed and Roundup OriginalMax in 2005 similar to the cost of buying both in 2004. This is exactly what we discussed earlier, i.e. competition in the chemical market with no patent will lead to lower price of the chemical, and the monopolist would like to reap the rent via increased price of its monopolized product. However, if the GURTs owner fails to obtain a patent, he could not secure his monopolistic position in the market. IPRs and GURTs are complementary rather than substitutes. Therefore, patenting does affect the monopolist position hold by the technology owner, which is consistent with the major players' vigorously seeking patent protection for their GURTs type technology (table 2).

Will GURTs take over the whole market?

If GURTs are commercialized, one argument is that the private seed sector has the incentive to incorporate GURTs into all the commercial varieties they are producing. In this case, V-GURTs will lead to serious concerns about food security and sovereignty. T-GURTs cause less concerns in this regard. We will examine farmers' decision in this scenario. For simplicity, we divide farmers into three groups: 1) those that already have adopted the commercial varieties and purchase seeds every year; 2) those that purchase seeds from informal seed suppliers and/or from the consumer market, and 3) those that use saved seeds.

Farmers will buy V-GURT seeds if and only if the net gain from the V-GURT seeds is positive and is greater than the net gain from the non-V-GURT commercial varieties or saved seeds. Since GURTs are viewed as a technology protection mechanism, it should be safe to assume that GURT seeds and non-GURT seeds are identical in performance and management except for the second generation gene expression and/or fertility. We also assume that the introduction of V-GURTs will not affect the output price, i.e., price of the agricultural product is exogenous. A farmer has a production of y

= $f(x_i, z)$, where x is the amount of seed being used, i denotes the type of seed ($i=1$ for GURTs, 0 for non-GURTs), and z is a vector of other production inputs. Let p denote the price of the agricultural output, w the price of the seed, and r the price vector of other inputs. In the static model, the farmer's profit function is:

$$\pi(p, w_{i,} r) = \underset{x_0, x_1, z}{Max}\{p \cdot f(x_0, x_1, z) - w_0 \cdot x_0 - w_1 \cdot x_1 - r \cdot z\}.$$

The farmer will choose GURT seeds if and only if

(IR) $\quad \pi(p, w_i, r \mid x_1 > 0) \geq 0;$

(IC) $\quad \pi(p, w_i, r \mid x_1 > 0) \geq \pi(p, w_i, r \mid x_1 = 0).$

Group 1 farmers are likely those in the developed world, where the IPRs are well established and enforcement mechanism is effective, therefore they are purchasing the commercial seeds every year. In this case, the static model is sufficient to study farmers' decision making because the dynamic model is a simple addition of the static models. If $w_0 = w_1$, then farmers are indifferent between buying GURT seeds and non-GURT seeds. For the producers, whether they would like to supply V-GURT or non-GURT seeds depends on the relative costs of the two. Incorporating the V-GURT technology into the seed requires additional production costs. However, the V-GURT helps in reducing the monitoring cost and other transaction costs in enforcement of the IPRs related to their commercial varieties. Therefore, we may conclude that if the cost saving is greater than additional production costs, then the seed producer would prefer to replace the non-GURT seeds with the V-GURT seeds. Moreover, if the price of GURT seeds is lower than that of the comparable non-GURT, group 1 farmers would prefer GURT seeds to non-GURT seeds. If, however, the cost saving is less than the increase in cost of production, then it does not pay for the seed producer to adopt the GURT technology. Therefore, whether GURT will take over the market or not in group 1 market depends on the cost structure in the seed producer side.

Group 2 farmers obtain their seeds from informal seed market because those seeds are comparable to the commercial varieties in the formal seed market but cheaper or more convenient to buy. If V-GURTs are incorporated into all the commercial varieties, then group 2 farmers are no longer able to obtain access to the improved varieties through the informal seed market. The informal seed market may supply only the traditional varieties, or those “obsolete” non-GURT varieties. Farmers would either purchase GURT seeds if the price is affordable (not necessarily lower than the non-GURT varieties sold before), or buy inferior substitutes in the informal market or just use the saved conventional varieties. The farmer’s profit function in a static model is

$$\pi(p, w_{i,} r) = \underset{x_1, x_{21}, z}{Max}\{p \cdot f(x_1, \phi \cdot x_2, z) - w_1 \cdot x_1 - w_2 \cdot x_2 - r \cdot z\},$$

where x_2 is the amount of inferior substitute seeds obtained from the informal market if V-GURTs is used, w_2 is the price of the inferior variety, ϕ is an efficiency coefficient of the inferior variety, and $0<\phi<1$, because the inferior variety does not perform as well as the commercial variety.

Group 2 farmers will choose GURT seed if and only if

$$(IR) \qquad \pi(p, w_i, r \mid x_1 > 0) \geq 0;$$
$$(IC) \qquad \pi(p, w_i, r \mid x_1 > 0) \geq \pi(p, w_i, r \mid x_1 = 0).$$

Group 2 farmers may be the focus group of V-GURT seed producer. They are likely farmers in the area where IPRs on plant varieties are either not well defined or not effective in enforcement. Group 2 farmers are not necessarily financially constrained; rather they and the breeders in the informal seed market are free riding the R&D of seed producers in the formal market, because the commercial varieties provide "free" breeding materials to the informal seed breeders and thus the informal variety could beat the comparable formal varieties at much lower price.

Group 3 farmers are most cited as the victim of V-GURTs, and they are the majority of farmers in the less developed countries and in resource poor agricultural communities. Group 3 farmers save seed for their own use and may also deliver them to the informal seed market for sale. However, we need to make clear how group 3 farmers could become victims of V-GURTs. If group 3 farmers are using the same strain of saved seeds for generations, then we hardly see how introduction of V-GURTs will affect their farming activities, - if they do not go to the seed market to purchase seeds anyway, then why would they care whether the seeds in the market all GURTs or non-GURTs? Group 3 farmers become the victim if they purchase the commercial variety in the first season, and then will save the seeds for planting in the following seasons until there is another improved variety in the market. We write this type of farmers' multi-period profit function as

$$\pi(p, w_{i,} r) = \underset{\{x_{1t}\}_{t=0}^{\infty}, \{x_{3t}\}_{t=0}^{\infty}, \{z_t\}_{t=0}^{\infty}}{Max} \sum_{t=0}^{\infty} \beta^t \{p \cdot f(x_{1t}, \theta(t) \cdot x_{3t}, z) - w_1 \cdot x_{1t} - p \cdot x_{3t} - r \cdot z_t\},$$

where x_3 is the amount of seed saved last season that are planted this season (since the output price is assumed exogenous and constant, the implicit cost of the saved seeds is the revenue they could have generated if being sold in the consumption market), β is the discount factor, $\theta(t)$ is a function for the seed productivity declining process, it is exogenous, and has the property $0 < \theta(t) < 1$, and $\theta'(t) < 0$.

Group 3 farmers will choose GURTs seeds if and only if

$$(IR) \qquad \pi(p, w_i, r \mid x_{1t} > 0) \geq 0;$$
$$(IC) \qquad \pi(p, w_i, r \mid x_{1t} > 0) \geq \pi(p, w_i, r \mid x_{1t} = 0).$$

However, the conditions above would be meaningful only to the seed producers' decision on whether or not to introduce V-GURTs seeds to this group of farmers, but not relevant to the concern of food security and sovereignty. In fact, as long as $x_{3t} > 0$, farmers could always switch back to their old fashioned production method if they found it does not pay to buy the V-GURTs seeds. One may argue that if the farmers plant both V-GURT and non-GURT seeds in their field, the potential cross-pollination may, in the extreme case, make the second generation of the non-GURT seeds sterile. Even if this unlikely case would happen in reality, this disaster could be avoided by farmers' retaining some non-GURTs seeds in their storage, and replant these seeds in the next season.

Conclusions

In this article, we discussed the mutual reinforcement effects of IPRs and biotechnology in recent years, and how that affects the agricultural biotechnology companies' strategy in designing their technology portfolio, i.e. the GURTs method at both variety level and enhanced trait level. We reported the development and the *status quo* of GURTs, and the major players' actions in this area. Both proponents and objectors of GURTs made strong arguments based on speculations that lack rigorous analysis. We discussed the major arguments by both sides, and made an effort to examine some major implicit assumptions hold by the objectors. We found that some assumptions are weak in their validity, however, more analysis will be needed to further examine the empirical validity of these and other assumptions popular in the opponents and proponents.

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