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Agricultural Biotechnology Risks and Economic Development: A Call for a Public-Private Partnerships to Stimulate Investments into African Biotechnology Industries

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Abstract

What makes or breaks the decision for an MNC to enter an emerging market beyond incentives for profit-maximization? What role exists for public-private partnerships as a mechanism for value capture in agricultural biotechnology investments into uncertain markets? The objective of the paper is to provide the necessary theoretical framework by which future research may empirically assess the discounted value and probability of R&D investments into the African agricultural biotechnology sector. A partnership model lies at the foundation for creating marketing channels between industries with high fixed costs and high social utility value. **S**timulating intellectual and scientific investments in agricultural biotechnology are contingent on prioritization of public policy, wherein optimal investment strategy into developing markets becomes a balance between providing adequate incentives for investment without compensating technological dissemination to smallholders. A strong regulatory environment not only ensures market power for the private industry and but forces change in the general expectations from and attitude towards the hybrid seed and agriculture innovation. It is, additionally, imperative to create a linkage between the private sector and the smallholder. Not only are multinationals currently the gatekeepers of intellectual capacity for agricultural biotechnology research, but also possess capacity to enter the market and provide products en masses. The lack of immediate profit incentives may be balanced by public sector partnerships that might cushion risks and eventually expand market opportunities for the smallholder.

Introduction: The Modern Seed Industry and Globalization

This paper was prompted by the question, "what is the influence of foreign direct investments in the seed industry in emerging countries?" Organization of the private seed sector has been characterized by firm consolidation and a shift away from purely agrochemical research into a world of high risk ventures in seed genomics. The implications for the structure of the industry challenged the central assumption in the questions stated above. That is, the central question was not so much a characterization of FDI in the seed sector, but rather ***which development strategies can by-pass obstacles of incomplete markets while stimulating economic growth?*** Effective public policy has been touted as the best method of stimulating foreign investments in high cost, high risk projects in areas in need of agricultural R&D.

Research on the agricultural seed industry in developing countries is vast and has focused on the effects of strategic pricing behavior on competitive structures as a result of monopolistic and oligopolistic tendencies of the seed biotech sector and, access to seeds by farmers through market mechanisms as a result of market changes. Generally, these studies have centered on how the factors influence product, process and institutional innovation (Speilman, 2003). Product research investigates improvements in cultivar varieties and productivity enhancements as a result of genetic improvements; process research accounts for cultivar methodologies, from plant breeding and selection through to genetic engineering.

Research on institutional innovation focuses on the social, economic and political relationship between the private and public sectors, agriculturalists and rural/urban consumer and will be the focus of this essay. The scope of research in this field has accounted for allocation mechanisms of R&D investments between public agents and the farmer or co-op and has followed the lifecycle of product development: addressing innovation channels, postulating on avenues for market introduction, acceptance, market growth and, finally, how to deal with obsolescence of a technology or process.

What has yet to be determined in agricultural development is how to best address "institutional innovation" in the presence of market failures. For the sake of example, let's consider a small-scale South African farmer in a village in Kwazulu-Natal. For him to simply participate in local markets, he needs to contend with a mode and method of transportation from his farm to the local market since interstate roadways have yet to be developed to the extent of connected the vast majority of scatter, rural villages to major towns. He also needs to address savings to buy seeds and invest in marketing his product, a stable and healthy supply of labor and weather. Idealistically biotechnology has endless potential for small-scale farmers to address only some of the issues. However, questions of how the farmer that would best benefit from this technology can afford to buy GMO seeds or maintain communications with extension specialists is still being investigated.

The research presented in this essay will address the following research question:

What public policy measures can best take advantage of the innovations in biotechnology to spur agricultural development in low-income countries, given the high risk, high cost and low-returns of these projects?

Innovations in effective irrigation, crop protection and yield have traditionally been at the forefront of economic development policy. Although most of the industrial world relies less on the agricultural sector as carrying the burden of leading and being a proxy for economy-wide health, agriculture is the most important economic sector in most of the developing world. Productivity gains have been stalled from regional-specific diseases, environmental factors and ineffective techniques. Biotechnology has played a role in ameliorating some of the issues faced by the smallholder by creating solutions for many of these problems through gene manipulation and seed development.

The technology undoubtedly holds promising solutions to benefit agriculture based economies. However, many countries have been hesitant in promoting research into biotech foods and crops for fear of loosing important external markets and general lack of information on the long-term health and environmental implications from genetic engineering. Biosafety policies are harmonized with the viewpoint that biotechnology will improve the economic base of the exporting country as well as encourage improved resource use (Herity, 2003). American and Canadian producers face less aversion to GMOs due to commercial opportunities to internal markets and environmental benefits that reduce production costs. In contrast, early in the 21st century, the European Union had in place a moratorium on importing any genetically modified products. From a strictly economic perspective, the production gains in North America by the use of biotechnology has the potential for flooding the EU market. As such, the Nuffield Council is perceived as a trade barrier rather than an ethical protest. African countries that begin to use crop biotechnology are in jeopardy of losing many EU consumers (BFTW, 2002). As a result of market threats from adopting biotechnology, there are many commercially and food security driven countries that are *averse* to adopting GMO technology. Zambia is an example of a country searching for food security and income generation opportunities yet will not adopt biotech policies in fear of losing the EU market. As a country frequented by droughts, floods and breaks in the supply chain due to weak infrastructure, Zambian farmers are restricted to certified maize and some vegetable seed varieties and tend to rely on farm-saved seed. Improved seed varieties and complementary inputs remain artificially high due to bureaucratic misconceptions on returns from improved seed varieties, limiting both production and sales of improves seed varieties (Muliokela, 2004). Agricultural productivity and household food security in Zambia is limited to improving seed production, as opposed to increasing cultivated land area, as well as improving national seed distribution system. In the case of Zambia, seed certification programs have been developed to protect farmer varieties and lower transaction costs within the market. Also, there has been general government support and investment to initial seed sector development

(Muliokela, 2004). Ultimately, the promise for improved productivity and general stability overshadows ethical doubts of the science.

Contrary to a public-sector driven research sector in the past, today the private sector hold the best resources to devote to research and development (R&D). With changes to the industrial structure of the sector, larger firms have an opportunity to invest in risky projects, such as regional specific crop diseases. At the same time, larger firms are driven by shareholder expectations and thus, evaluate projects based on profit margins which necessarily excludes many agricultural genomic research aimed at developing countries. Smaller seed research facilities are often inadequate to address genomic research questions. It is currently difficult to attract necessary investments into the commercial research and development sector for regional-specific diseases due to perceived and actual low market returns for these investments, distribution challenges in countries with poor market infrastructure and lack of awareness for agricultural research oriented in developing countries. Parallel importing and compulsory licensing have also created disincentives for future investments. Finally, the high fixed costs of conducting research often precludes the ability to offer these technologies at low-cost for the smallholder. In the end, the farmer who will end up using the seeds are cultivating to serve local food needs. Hence, the issue becomes one of creating affordable access to hybrid seeds without compensating incentives (i.e. returns on investment) to invest in such opportunities.

The essay attempts to address to question of how to improve incentives to invest in seed genomic research in African countries by synthesizing information from related sectors, such as pharmaceutical and information technology and other industries similar to the organization structure of the biotechnology industry. The findings reiterate that it is insufficient to simply reiterate the role of the public and private sector in disseminating productivity-enhancing technology and poverty reducing strategies. Rather, the gap between potential for investments and probability for returns on investment are a function of two elements: an appropriate economic model and public-private partnerships modeled after successful ventures in the AIDS and Tuberculosis research sectors. I propose that research be invested in the potential for real options theory as a method for better articulating the extent to which investments will be of value to its stakeholders and affected by technical uncertainty, regulatory uncertainty and scientific uncertainty. In an industry characterized by high-costs, support for venture capital markets through public-private partnerships is unequivocally the best public policy instrument because it bridges institutions to address transaction costs and risks. The essay introduces the next step: a best practice model based on the work of the Global Alliance for TB Drug Development.

In Section 2, the state of the seed biotech industry will be characterized with respect to its private and public sector structure in 2005 and public policy framework. The current industrial structure will be described and put into context with the Schumpeterian model of innovations (Section 2.1). In light of a consolidated industry, the need for effective patent laws will be discussed as a tool for harnessing research for application to problems in developing countries (Section 2.2). The role of public sector will be presented (Section 2.3) and then partnership potential between the public-private will be explored (Section 2.4). The best practice model will be discussed in Section 3 and the economic model will be presented in Section 4 and applied in an example to investments in the Kenyan seed industry (Section 4.1). Section 5 concludes with policy recommendations and future research goals.

Section 2: Review of Literature

Section 2.1: Industrial Organization of the Agricultural Biotechnology Sector

Previous literature in this field has reiterated the ability of the private seed industry to fostering well-developed market structures in countries where multinational corporations (MNCs) decide to invest and it's role in advocating and initiating the process of developing a system of intellectual property in the country's public policy system. The trend towards consolidation (discussed in greater detail below) has in some respects "synergized" research capabilities with local start-ups and public firms, has allowed for economies of scale and scope to override fixed costs associated with the R&D costs idiosyncratic with the biotech industry.

The primary source of genetically modified (GM) crops today is the private sector (Sithole-Niang, 2004). Thus, many economists have advocated a pure private sector approach to accelerating technological growth in the developing world because the private sector offers the best opportunities for technology transfers and commercialization (Barton (2004), Martin, S and Scott, J (2000)). The private sector can import technologies with greater efficiency due to differing goals. As opposed to pure research goals, there are factors such as profitability and cost-efficiency that improve the selection process of various investment opportunities (Wagner, 1999). Currently, the international seed industry has been the largest investor of seed research in commodity-export oriented countries, such as Brazil and Argentina (Appendix: Table 1). Most field trails of new biotechnologies are conducted by private MNCs (Pray, 1999).

The pubic policy emphasis on promoting private sector growth in the seed industry is a departure from the rhetoric that drove success in Southeast Asia during The Green Revolution. During the 1960s and 1970s, introduction of improved and modern variety of seeds was possible with a well integrated institutional system. Appropriate resource management techniques and introducing complementary inputs, dramatically increased agricultural productivity and stimulated economic growth within a span of 20 years (World Bank, 2003). The public sector influence resulted in a public goods nature of agricultural R&D. Institutions were able to manage costs and risks of long-term projects in areas with high degrees of uncertainty and allow of wider dissemination of knowledge through a vertically integrated system via an enabling public policy regime (Byerlee et al, 2002).

A decade ago, the commercial seed industry was highly concentrated in industrialized countries, with a calculated global seed market of $50 billion (US). The Erosion, Technology and Concentration (ETC) Group estimates that the top 10 seed industries in 2003 controls $23,000 millions worth of the commercial seed market and accounts for 31% of commercial seed sales (ETC, 2003). Most MNC concentration is evident in the largest food crops, such as maize and soybean. In 2003, the global market value of GM crops is estimated to be $4.50 to $4.75 billion ($4.0 billion in 2002). This value for 2003 represents 15% of the $31 billion global crop protection market, and 13% of the $30 billion global commercial seed market. However, for maize alone, four companies control over three-quarters of the commercial seed market (ETC, 2003). For 2005, the global value of the GM crop market is projected to be at least $5 million, with over 67.7 million acres devoted exclusively to transgenic crops in 18 countries (Davis, 2004).

As the empirical evidence suggests, the biotechnology market is dominated by few firms with significant market power. Mergers, acquisitions and strategic alliances are typically between large and established firms and, technology start-up companies (Appendix: Table 2). According to the Economic Research Service of the USDA, Monsanto best exemplified the trend towards consolidation and led the fundamental shift in the industry focus from agrochemicals and fertilizers into genetics and life sciences. Between 1996 and 1998, Monsanto acquired a biotech company (Calgene) and numerous seed companies (Asgrow, Corn States Hybrid, DeKalb Genetics, Holden's Foundation Seed, the Plant Breeding Institute Cambridge, Sementes Agroceres and Cargill's foreign seed business). Are biotech investments adequate methods of stimulating industrial development? The US Federal Trade Commission assesses industry competitiveness in terms of impact on innovative capacity (Giannakas et al., 2001). Indeed forward and backward integration not only by-pass transaction costs of entering risky markets and initiating field tests, but leads to commercialization of plant biotechnology (Bijman, 2001). Brennan et al. (2001) found that MNC concentration in the US biotech sector was complementary for corn- and cotton-related patents, but substitutes for soybean. It must be noted that multinational seed companies are able to improve overall efficiency and competitive advantage of the sector. Vertical integration with smaller firms still in phase 1 of a research project, however do not generate profits because they are unable to attain economies of scale and scope with respect to most aspects of the product pipeline (i.e. plant breeding, variety registration and marketing).

Market structure is invariably a determining factor to the success of a firm in an R&D race, in addition to public sector R&D and intellectual property rights. Phillips (1971) suggested that the market structure of R&D influences the market downstream. The gains realized by smaller, local seed companies in developing regions are largely afforded in terms of increased research capacity and ability to avoid the fixed costs of the R&D process through market imperfections, such as knowledge spillovers (Alex et al., 2002).

The late Schumpeter model from *Capitalism, Socialism and Democracy* (1975) will serve as the theoretical basis from which the current agricultural biotechnology seed sector will be evaluated. Unlike Schumpeter's earlier theory, where technological advances are characterized by constant entry and regeneration by innovative firms causing displacements of "out-dated" firms, his later model introduced the concept of barriers to entry. For example, as mentioned earlier, the agrobiotech industry is characterized by high fixed costs and potentially high profits for patent-holders of a specific technology. The uncertainty of successful product development is balanced by the potential of certain market power and corresponding existence of economics of scale from this "winner takes all"-patent-based specialization in innovative processes. Larger firms with greater technological resources and market power enjoyed positions of static power. These firms would then use this market advantage to finance risky, large-scale R&D activity and leave society better off (Martin S. and Scott, J, 2000). However, the game is not lost for those who do not finish first-as 'creative destruction' implies: the sole holder of a technology is bound to be imitated or superceded by another-better- innovation. Research on Schumpeter's model of technological change in non-competitive market conditions is exhaustive and appropriate from which to view the current high-tech agricultural market because it is an industry where risk is inherent in the research, development and commercialization process.

Supporting Schumpeterian views on innovation, Brennan et al (2001) show that market concentration in the US biotechnology industry could increase appropriability, that is the opportunity to bring a product from concept to market. Success could increase R&D intensity in the forms of economies of scale and scope. For example, Baker (1998) suggests that monopolization in Aspen skiing resorts or Kodak actually encouraged fringe innovation in some industries by increasing the expected payoff to such innovation without reducing the incentives for dominant firms to innovate. Hayenga (1998) stresses that there is currently insufficient evidence of price setting by mature firms in oligopolistic seed industries. As a result of concentrating their research and marketing resources, the end-user gains from high productivity and efficiency gains (Thayer, 2002).

Martin (1998) suggests that product-market competition will reduce expected profits before and after innovation but, reduces pre-innovation profit relatively more and this increases private incentives to invest in innovation. As the concentration of firms active in innovative activities increases, competitive pressure will reduce incentives to innovate in the industry, as a whole. Specifically, risk aversion may increase with increased concentration, and crowd out the smaller entrepreneurs, who are potential risk takers and sources of innovation. Ahn (2002) also summarizes the effects of market power as an issue between the expectations of *ex post* market power as an incentive to invest and *ex ante* market power as a means of reducing uncertainty associated with excessive rivalry. There does exist a "two-tiered" structure by which a dynamic relationship exists; the yet to be profitable start-up that pioneer research of biotech processes pertinent to regional agricultural issues and the multinational which is typically a late-comer into the market. Although static competition might appear almost non-existent, the expectations of short-run market power is a necessary condition for dynamic competition. Industry concentration serves as an incentive for expansion by spreading the sunk costs of basic research (Breenan et al, 2001).

Ultimately, the limited empirical research does not resolve any questions regarding the relationship between concentration and R&D activity (Oehmke, 2001). A strict reliance on market structures can result in underinvestment in innovative processes due to limited appropriability from the market as a whole, limited knowledge spillovers or monopolization of government infrastructure: each of these elements overrides the potential for consumer surplus as a result of market power (Martin, S and Scott, J, 2000). However, profits from market powers can also provide firms with leverage to innovate despite inefficient markets. This is the most powerful argument for private sector expansion in agrobiotech industries. The inability for local seed companies to gain access to complementary inputs such as the presence of credit institutions, distribution mechanisms (marketing programs) and opportunities for bureaucratic collaborations with the private sector is largely driven by the presence of monopolistic industries that capture rents, overestimating managerial effort and leading to greater market inefficiencies (ETC, 2003). Madhok (2002) suggests that the extent of influence of innovations to incumbent firms in the agrobiotech industry is influenced by home country embedded-ness of technology creation and absorptive capacity for commercialization. The general positive spillovers from technology transfers *may* be adversely affected by higher market prices upon entry of MNCs through strategic alliances with strong local firms. As the trend towards privatization in the seed industry continues to be predominated by large multinational seed industries, the exclusive rights to the market leads directly to a strong market position. Naturally, value placed on technology as a result of exclusively further drives up the market value, despite regulatory cushions or consumer uncertainty.

With new models of market structure and competition, the case for strict market power is no longer sufficient. Similar to Schumpeter's earliest model of innovation, new entrants have the potential to aggressively experiment with new technology because they are not overburdened by corporate goals and large management structures. The smaller, goal-oriented firm may actually be a driving force for innovations and also forced to innovate themselves (Ahn, 2002). Garcia and Velasco, 2002 studied the European biotechnology industry and introduced the dyadic notion of competition and cooperation ("co-opetition"), where strategy is a function of industrial relationships rather than structure. Specifically, co-opetition occurs when 2 firms form a strategic alliance and trust towards a common goal, yet compete in other aspects. This notion extends to the shifting political mind-frame of the 21st century ag-biotech venture capitalist.

Competitive pressure will always be the most reliable free-market mechanism of checks and balances, with the power to stimulate innovative activity, consumer surplus, and firms are more apt to increasing productive efficiencies so as to secure rents that better reflect marginal gains in productivity (Ahn, 2002). Competition is conducive to Darwinian innovation and growth or a 'neck-and-neck effect', forcing firms to speed up adoption of new technologies and innovate to survive. In high-tech industries in emerging economies, product market competition is more common, since it is characterized by as a market of substitutability between new and old production methods.

Section 2.2: Why Plant Property Rights have come to matter

Grossman et al. (1991) argues that biotech companies with vested interests in agricultural inputs and trade enter the seed industry to diversify their activities. It is the existence of intellectual property laws that guarantee exclusive rights over technologies, and as such remains the source of barriers to entry and decisive factor of taking risks in a potential market: market power becomes a reality with a system of property laws. Intellectual property rights in the form of patents have greatly influenced MNC strategies on investing and controlling dissemination of proprietary knowledge. Plant technology is, naturally, a biotech MNC's main commercial asset and is used to guarantee a continuous stream of income after years of R&D. It is the prospect for recuperating the start-up costs from licensing patents which stimulates the financial investment in new technologies and attracts new investors.

Fifteen years ago, Vitamin A deficiency afflicted nearly 400 million of the world's population, of which a quarter were children. Without Vitamin A, children develop partial to complete blindness, respiratory problems and diarrhea (Sommer, 1990). For the poor, the majority of caloric requirements are from rice grains, a food without beta-carotene, the precursor to Vitamin A. So, Swiss scientists introduced 3 genes: two from daffodils and one from a bacterium that produces beta-carotene (giving the rice it's golden color) with the ultimate goal of transferring the genetic materials to local varieties of rice in developing countries (Khush, 2004).

Unfortunately, golden rice not only used 70 different patented materials, but these rights belonged to 32 different entities (countries and universities). How can golden rice reach the poorest farmers free of restriction? In the end, the inventors were able to circumvent the IPR issues by issuing the technology under the general principle of "technology for humanitarian purposes" sponsored by Syngenta. Humanitarian use mandated that Golden Rice be made available to resource poor farmers who make less than US$10,000 per years. Humanitarian license terms allowed the inventors to secure rights from several companies, without forsaking commercial rights and possibilities. To date, the Philippines, India, China, Vietnam and Indonesia have secured licenses to Golden Rice. Although this case is an illustration of one of the first successful public-private sector partnership, it also shows that tapping into the genetic potential of a crop variety afflicted with disease and productivity hurdles is not a simple matter of R&D development and marketing. The use of proprietary technologies might cause costly inventions to never reach the end-user either because of costs of ownership or limitations to commercialization. Golden Rice was a rare case of socially-conscious inventors and effective legal resources to avoid patent hassles after the fact. It reflects that if an invention is sure to benefit a large mass of people around the world, duty might (and in this case, did) supercede pure profit-motives. In most cases, this framework will not apply, especially when research has not reached the development stage due to costs impediments or without a clear profit margin as a result of appropriation.

The hybrid seed industry's market security is directly related to changes in intellectual property rights (Barton, 2004). Hybrid seeds are valued for commercial gains from significantly higher yields and, proprietary incentives are a necessary mechanism encouraging innovation and R&D. For most hybrid seeds, however, there is an added barrier of protection as many seeds do not breed true-to-type offspring. In cases where 'biological' protection is non-existent, Plant Breeder's Rights have been adopted in most countries under the provision of the international Union for the Protection of New Varieties of Plants (UPOV) as a uniform system for variety protection and quality control in industrialized nations. Without UPOV laws, a breeding parent can be a genetically altered variety (i.e. a plant where a specific gene has been introduced artificially). A competitor can legitimately transfer this gene by cross breeding and market the resultant variety as his own, with the gene originally discovered in the breeding parent. Without laws that account for such occurrences and protecting the transformed gene, a breeder would be less likely to discover genes, create trangenic seed varieties and introduce them into the market (Barton, 2004).

Once novel and useful inventions of processes are patented, the ability to capitalize on patents is highly dependent on mechanism of patent and intellectual property protection (Nuffield Council, 2004). Without divulging into patent law, holding a patent gives the owner full control over who may obtain a license for use of the technology for a given period of time. UPOV is largely viewed as the most effective framework for legislative *positioning*. Aside from the obligations established under the Trade Related Aspects of Intellectual Property Rights (TRIPs) agreement of the WTO, underdeveloped frameworks threatens cut-offs from biotech investment opportunities and access to proprietary knowledge that fail to go beyond the provisions guaranteed by UPOV. UPOV serves only as a necessary guideline for clarifications and limitations on patent law legislation and is certainly not sufficient.

UPOV 1978 initially outlined 3 criteria for varietals protection afforded to plant breeders: 1. Distinctiveness[1] 2. Uniformity and, 3. Stability [2]. For example, consider a transgenic insect resistant variety. Ownership at stake includes: rights for the germplasm, 2 patents for the selectable marker gene, 2 patents for the trait to be incorporated, 1 patent for the transformation technology, and 2 patents for the gene expression technology (Bijman, 2001). A patent holder may then license the rights to a germplasm with no obligation to license the corresponding technologies it owns. The classic case illustrating the potential insufficiencies of UPOV is that of

[1]By distinctness, the UPOV means a variety of plant which is 'clearly distinguishable from other varieties whose existence is a matter of common knowledge'

[2]Relevant characteristics of protected plant variety remain unchanged either for a specified period or after repeated propagations or cycles of propagations'

Agracetus[3], the first to obtain patent protection for the genetic engineering of cotton plants and transgenic soybeans (Bijman, 2001). The broad nature of the patent protected both the transgenic plant and the technology, implying that Agracetus would have exclusive rights to all transgenic soybeans and cotton plants, regardless of technological methods and thus, tremendous commercial power.

The current version of UPOV viz. UPOV 1991 added 'new' to the description, to complete the description of plant patents to be "new" and "distinct". The newest amendments also broadened coverage of patent laws to cover plant varieties of all taxa. UPOV 1991 gives an option to national governments to prevent farmers from the privilege of retaining or re-using seeds for self cultivation. In other words, the breeder of a cosmetically bred variety would have to buy genetic dependency rights from the derived variety prior to commercializing the derived version.

IPR policy plays a crucial role in agricultural investments as a signal for a market where risk taking behavior will payoff. Low discount public funds for plant breeding has induced countries like India to develop policies modeled after UPOV , based on the implicit assumption that private funds for R&D in plant breeding will 'crowd in.'

Further, technology licensing agreements complements the development of an oligopolistic, yet globalized marketplace. Licensing allows a firm to maintain market power and control over their innovative processes while minimizing the potential start-up costs of market development (Bessey et al., 2002). As an intermediate form of knowledge transfer, licensing ultimately has the benefit of affiliation with established local partners and less investment risk (Krattiger, 2002). Not only are intellectual property rights used as a mechanism of market protection but, it increases exporter liability to infringe on foreign IPR. Barton (2004) suggests that with effective laws, IPR can be beneficial in creating location-based trademarks in developing countries, where geographic indicators can be used as product identification and

[3]Agracetus is now owned by Monsanto

differentiation signaling quality and trust. IPR regimes play a key role in influencing the evolution of innovations (discussed in detail in Section 4). Arguably, patent laws that protect the seed investor from gene discovery, transformation and any transformed plants with the patented gene are needed. Such laws also facilitate commercialization of varieties developed in the public sector.

Barton (2004) however, suggests that IPR has differential effects on research between ornamental, horticultural and field crop varieties. That is, for crops such as wheat where hybrids are generally not used, IPR creates very little inventive for additional R&D as opposed to maize where IPR is a necessary form of protection (Barton, 2004). In many ways complying to protection laws are cost prohibitive for local seed firms. Tripp (2003) claims that seed sector regulation is not a prerequisite for seed system development because regulation can actually be perceived by farmers and smallholders as a hindrance to production development. The cost of obtaining regulatory clearance for crops, such as Bt maize, that are registered in the main export markets range between $7 to 15 million dollars (De Greef, 2004).

Gravel et al (2004) considers a similar industry, the electricity power grid investment, and suggests that for irreversable investment decisions lengthy and costly regulatory review processes increases market uncertainty-regulators should strive towards predictable, fair and short processes. Currently, many sub-Saharan countries insist on food crop certification process which remains a cost prohibitive for smaller seed companies and a time cost to larger firms. De Greef (2004) expands upon the prohibitive nature of international regulatory services for the public goods sector. Most regulatory compliance work for large-scale, commercial agrobiotech projects are in-house for companies with the legal and administrative capacity.

The most viable options for accessing proprietary technologies include unilaterally accessing technologies, purchasing it and material transfer and, licensing agreements (Khush, 2002). The first of the three options merely suggests that it would be legal for the public sector to copy a technology without seeking permission from the owner if the patent for the technology has not been lodged in a country where it is used or exported to a country where the technology is protected. This option is most seen in countries with fragile national agricultural research systems and ill-defined regulatory frameworks.

The purchasing option is most viable for situations where knowhow exists in the private sector of a technology which would be of social benefit, but market uncertainty impedes private sector development of the technology. The International Rice Research Institute (IRRI) which purchased the rights to *Bt* gene owned by a Japanese firm, Planttech, made the rights to the gene publicly available subject to royalty costs. Similar scenarios have also played out in Latin American national agricultural research centers. Khush (2002) suggests that a contract to participate in a agricultural development process in exchange for retaining ownership of the product with the private sector via a competitive bidding option would be a viable strategy in situations when development of products that would otherwise not go into product development due lack of foreseeable profit-motives could materialize.

Currently, material transfer and licensing agreements (MTA) are favored due to minimal upfront costs and lowered risks because negotiation for the use of the product occurs after the value of the product is fully known. However, MTAs are usually limited to use for the research phase, leaving legalities and development for commercial use to a later stage. Also, since the success rate of the product is known, the higher expectations on returns to investment lead to higher costs. The prospects of gaining first-mover advantages with such technology is an especially fruitful strategy in economies that have yet to be introduced to innovative products. MNCs successfully capture and secure profits since farmers must return year after year to procure new seeds from the seed marketer to sustain his new found high yield output.

Hence, the extent of and conditions for seed demand are factors to consider from the production side; improved technologies are far superior in yield capacity than traditional landraces, especially for hybrid seeds capable of increased yield under limited availability of water and certain management practices (Maunder, 2000). Although hybrid seeds have been widely adopted by small-scale farmers in markets where price controls have kept seed-to-grain prices low, farmers are far more willing to forgo controlled pricing and willing to pay as much as double for seed from an MNC with the reputation and assurance for quality seeds. Hence, one might argue that intellectual property rights with provisions for material transfer and licensing agreements will not only favor of the private industry as a necessary way to encourage innovation and growth, but a valued requirement if effective varieties are to reach the African, Asian or Latin American farmer.

Enforcing and adjusting intellectual property rights policy will not encourage additional private sector investment in these countries, as intended, unless there is harmonization between biosafety and patent law expectations between countries sharing similar agricultural markets. To gain an understanding of the future of biotechnology dissemination in the seed industry in developing countries, it is imperative to realize the reasons for stronger, progressive and enabling IPR policy. Expectations on biosafety are especially important in the agricultural development context because of the fragility of the raw materials supply chain and prospects of expanding into European and American markets (Nuffield Council, 2004)[4]. Biosafety regulation complements producer-side quality assurances by instilling confidence in newer technologies and creating a proxy for the social value of certain technologies (Sithole-Niang et al., 2004). Clearly, the priority for regulatory and trade policy with respect to stimulating biotech investments in developing nations is the ability to improve seed demand, concurrently with the increase effort in the production side (Tripp, 2003). Indeed a regulatory environment is a mechanism for accessing proprietary technologies by the public sector from the private sector, but legal measures also include legal and business options for varietal protection of hybrid crops developed by individual farmers and co-ops. For the poorest nations, the prospect of patent ownership is worthwhile as an investment catalyst only if there is a substantial commercial market for the hybrid variety. While a rigid regulatory framework increases the perceived costs and anticipated time to future investment projects by increasing time to realize investment projects, the most important

[4]The Green Industry Biotechnology Platform is a trade organization promoting these concepts of "ethical capital"

implication of redefining the proper balance of regulatory systems is the guarantee of returns to investment via a compliant market.

Tripp et al (2000) suggest that quality controls should be shifted 'downstream' by not only advocating consumer awareness, but also improving capabilities for ensuring quality control in the production-side. The current form of regulatory process and approval in the seed industry (in the form of variety registration, seed certification and quality control) ensure varietal safety and physical quality. Nonhybrid crops, except for vegetables, have had less success as products for opportunity in overseas markets (Maunder, 2000). In the case of spring wheat from Dekalb, although over 50% of the Argetinian market accepted the product it was not as profitable as marketing smaller grains in Europe. As a result, a much less risky approach to seed introduction has been by way of exports and licensing arrangements with established indigenous businesses. For example, Zimbabwe is currently transitioning from a public seed sector to a semi-private seed co-op which must start forming technical collaborations with U.S., South African, Zambian and Kenyan seed companies (Maunder, 2000).

Tripp (2003) offers the example of Kenya's policy for accepting Ugandan or Tanzanian varieties that have been tested and approved in their country of origin. Of course this idea of policy harmonization is not a peril to seed industry development in Sub-Saharan Africa. While the US does not have a mandatory variety registration or seed certification process, the European Union requires all varieties be certified and registered. However, the major difference between the apparent divergence of policy scenarios between these industrialized and developing centers is the attitude on existence and promotion of *voluntary* private certification agencies (Tripp, 2003). Although the regulatory framework for varietal introduction via the private sector is shifting to a more enabling environment, the ability to register and release new varieties of seeds is still subject to a tougher approval process compared to the United States (Tripp, 2003). The incentive structure exists in the form of marketing reputation of the seed firm and quality of production. Sithole-Niang et al (2004) report that the number of approved GM crops in developing countries is largely limited to insect-protected cotton due to ease of approval, since cotton is not a food crop and thus not subjected to food safety concern at home and for export.

Section 2.3: The Modern Seed Industry and the Public Sector

Currently, low purchasing power in a prospective economy in conjunction with a highly oligopolistic market sustains barriers to competition for local seed research firms and encourages higher price of seeds. New technologies have tended to displace those farmers that are unable to afford the agronomic changes needed to meet the demands of the growing food industry in most developing nations. Indeed one may argue that this simply creates a market where only the most efficient survive, the disparity amongst those who 'survive' in the market is not necessarily a function of true superiority in productivity, but rather access to extension resources. MNCs introduce better quality technologies that previously had not existed within the economy, however without competition and balance in the market, there are less incentives to encourage better technologies and research (Barton, 2004). The public sector does maintain the level of competition, participation of the public sector exists in a limited capacity, with majority of funding and execution highly dependant on the public sector (Falconi, 1999).

Although most plant genome research occurs in the private sector, there is little focus on agricultural production needs in the developing world (Barton, 2004). While cereal crops, such as maize, wheat and rice are traded both in domestic and international markets, sorghum, barley and millet are cultivated on marginal agro-ecological land and subject of significantly less R&D expenditure from both foreign public and private sectors. The majority of varietals come from local public institutions, such as universities and most commonly national seed and agriculture research centers.

Traditionally farmers produced seeds by saving and selecting seeds for planting from the best in their harvest (Grooseman et al., 1991). Until the 1960s, the seed industry consisted of small and medium-scale firms and cooperatives serving a local and at most a national market (Grossman et al., 1991). The modern seed industry has been responsible for agricultural modernization by introducing new hybrids and plant breed and seed production techniques. Hybrid seed technology ensures greater uniformity and higher yield although at a much higher cost than non-hybrid varieties (Groosman et al, 1991). Easy access to genetically altered seeds to the African farmer remain ineffective in facilitating dissemination of biotechnology to rural markets due to the high cost of the seeds. In 2002, of the 130 million acres of land devoted to GM crops, 0.2% was in Africa (Bread for the world, 2002). None of the GMO products in 2002 specifically addressed the idiosyncrasies of the African agricultural market (Appendix: Table 3).

Seed ventures by the private sector in maize, sorghum, sunflowers and wheat, as examples, have been successful in Argentina, Brazil, Mexico and Thailand. Not surprisingly, the beneficial impact of biotechnologies have been on crops of high economic importance Crops associated with a lower or not existent comparative returns on the world market, yet important in developing regions, have limited the potential for attracting research-oriented activities into Africa. Beyond that, the basic technologies introduced to the market tend to focus little on regionally important food grains and improving agronomic traits such as yield and insect and disease resistance (Brennen, 1999).

In Falconi's (1999) study of the biotechnology industry in Mexico, Kenya, Indonesia and Zimbabwe, each country's private sector research used mainly less advanced and thus, less costly, techniques which are closer to the market than more expensive research techniques because of the degree of risk associated with more advanced research. For the sake of compensating R&D costs, the most progressive research has concentrated on quality concerns of the developed market. Inadequate and low levels of research have resulted in lack of high yielding varieties and disease resistant varieties pertinent to smallholder needs. Although the private sector is may seem irrelevant to meeting the needs of the smallholder, there are opportunities for idealistic market exchanges; for example offering GM seeds at marginal cost pricing while recouping research expense by selling to large scale farmers at market prices (Barton, 2004).

The public sector, on the other hand, finances around 90% of total agricultural research in developing countries (Appendix: Table 4) (Pray and Deininger-Umali, 1998). Research capabilities vary between national agricultural research systems (NARS). Type 1 NARS posses the capacity in molecular biology to develop new products for specific needs (India, China, Mexico and Brazil) whereas Type 2 NARS has the capacity to borrow and apply molecular tools (Thailand, Philippines, Indonesia, Colombia, Argentina and Kenya). Most of Africa falls into Type 3 NARS, with simply capacity to borrow and apply technologies. It is in the third case where national research centers have no regulatory framework in place to even import and test transgenic products (Khush, 2002).

Maunder (2000) well-articulated that the limitations faced by private sector development can work only with partnerships with the public sector. Falconi (1999) contends that the public sector was always essential as a counterbalance to the private industry in the presence of inefficient agricultural market structures. The Consultative Group on International Agricultural Research (CGIAR) replaced approximately 60% of the rice and wheat for high yielding dwarf varieties during the Green Revolution. It was particularly financial investments into seed development in Asian and Latin American countries, rather than importing seeds developed in developed countries, that was perceived as the most beneficial form of public investment during the Green Revolution. Since the Green Revolution, these national agricultural investments centers have grown at tremendous rates in the emerging economies such as Brazil and China. These institutions provide an international network of field experts, conduits between farmers and technology by addressing all biotic and abiotic production constraints and guiding programs that maximize public benefits from technological innovations in agriculture (Barton, 2004). Varieties developed in the public sector can also be introduced to the market at competitive prices compared to the private sector varieties. Public sector assets also include a wide range of evaluation networks, expertise in breeding, familiarity with local growing conditions and access to seed delivery systems. However, Wheeler and Berkley (2001) identified transparency and public scrutiny at the public sector level as the deciding factor in a successful partnership.

Section 2.4: Public-Private Partnerships in Biotechnology

Without the private sector, progress made by the public sector in promoting cutting-edge research is drastically slowed. Although public-private relationships are highly desirable from the perspective of social welfare, there is little incentive for private sector participation. Tripp (2003) explains that the public institutional structure of the current seed industry in Sub-Saharan Africa makes is even more difficult to improve incentives for private sector risk-adversity due to lack of competition, acquisition of domestic firms and, complexity of research goals and strategies for the public African agricultural sector (Barton, 2004). Although Brennan et al. (2001) suggest that public sector R&D has a relatively quick impact on private sector R&D intensity, without the necessary data on the size, structure and content of the public sector at a national level, there is very little to support an informed policy decision to stimulate private investments (Falconi, 1999).

As public sector research intends to address smallholder farmer issues by adapting technologies developed by the seed industry, it finds itself downstream from private sector research (Barton, 2004). Falconi (1999) found that only a few public-sector research organizations use advanced biotechnology techniques and most local start-ups which can potentially enter into strategic alliances with an MNC are only in the first states of developing research capacity. As such, only the largest local seed companies can exploit research and technological capabilities.

A partnership between biotechnology firms and research centers in the creation of new information and technologies typically works as follows: Research centers collaborate as partners with larger biotechnology companies that are able to best realize the technical and commercial potential of research findings, i.e. provide risk funding for commercially attractive activities that are commercially attractive as identified by companies and academics. The partnerships expect collaborating companies will ultimately manufacture and distribute the final product. The basic incentive to accomplish this is by granting the company exclusive patent rights to the product while research centers provide access to the developing world markets.

Rarely are crop diseases with minimal commercial return are targeted. Collaborations between the private and public sectors usually include either private firms simply donating technology, institutions building upon existing biotech tools or genuine information and knowledge sharing. What are the "best practice" models of partnership currently in place where the public sector can maximize their societal goals without compensating the private sector's responsibilities of living up to shareholder expectations on profit margins given investments into product development. Since the mid-1990s several biotechnology products were introduced to the developing countries either through patent agreements facilitated through partnerships between the private and public sector. The following are examples of such collaborations:

Example 1: Pioneer Hi-Bred and the Agricultural Genetic Engineering Institute (AGERI) in Egypt worked together to develop a novel *Bt* strain that was introduced into locally adapted varieties of corn to develop insect resistance in those varieties (Khush, 2002). The project itself was funded by the Agricultural Biotechnology Support Program (ABSP) of the USAID at Cornell University. This project is a good characterization of the extent of investments necessary for high-tech development. AGERI scientists had to be trained in order to properly characterize the gene and subsequent transformations. The case of unique in that Pioneer was granted access to evaluate novel *Bt* proteins and genes patented by AGERI, i.e. ownership and commercialization of transformed maize belonged to the public sector and was made available to the private sector for use in the markets they served.

Example 2: In another example where ABSP was the supporting mechanism, Syngenta (ICI seeds during the time of the agreement) and the Central Research Institute for Food Crops (CRIFC) in Indonesia collaborated to develop tropical maize varieties resistant to Asian corn borer. Similar to the AGERI case, Indonesian scientists had to be trained on using transformation technologies. This example is used to illustrate the challenges encountered by private-public collaborations due lack of knowledge on IPR. In this case, the differences in development and protection provided between national laws and lack of legal management capacity in the public sector served as a major impediment to negotiating technology transfer agreements. Currently, NARS type 2 and 3 lack the knowledge necessary to properly negotiate such agreements with the public and private sector.

Example 3: In a project between Monsanto and scientists at the University of Hawaii to develop ringspot resistance in papayas, an extensive network throughout Southeast Asia was not only developed for the sake of R&D, but included specialists to address the impact of the research on income generation, food production, and nutrition impacts for resource poor farmers. Moreover, the research scientists were trained beyond their areas of specialty to include biosafety, food safety and IPR management. In many respects this model was successful; field trails were started in Malaysia and Thailand. In this case, it was the regulatory process in many of these countries that slowed the development process. Infrastructure problems within the government included inadequate staffing and knowledge of existing staff in bureaucratic roles to address biotechnology work (Esscaler, 2003).

Example 4: The best example from Africa is the case of virus resistant sweet potato in Kenya. The feathery mottle virus (SPFMV) has afflicted production yields throughout Africa, with up to 80% yield loss in some parts. In 1999, the ISAAA brokered a partnership for the development for SPFMV resistant sweet potato though biotechnology. The Kenya Agricultural Research Institute (KARI) and Monsanto, along with research support from ABSP and the Mid-American Consortium formed a partnership where Monsanto actually donated a royalty free license to virus resistance technology for application to sweet potatoes. Training and internships provided for Kenyan research scientists and the establishment of biosafety structures, IPR protection and technology transfer mechanisms have all helped the GM sweet potato reach station trails. Moreover, this project fostered the first field test of a transgenic crop in any Eastern and Central African country.

Section 3: In Search of a Model Beyond Agriculture

Krattiger (2002) describes the decision process of an MNC entering international markets as two-tiered. A company must choose between the option of exporting goods into a country or producing goods in the target country. Then, the company must decide between the option of establishing foreign affiliates or some form of local production through joint venture or establishing a firm without a strategic alliance. It is most likely a risk-averse MNC chooses a licensing agreement through a strategic alliance with a well-established local research entity that has enough research capacities to carry out and build upon patented techniques for local adaptation. Once this decision is made, however, the firm goes through a sequential investment process.

Once pursuing the decision to market a variety in a partnership scenario, the firm automatically subjects itself to incurring upfront costs during the regulatory process. Once they enter into the regulatory process, the probability of attaining approval is a matter of the perceived social welfare benefits by the regulator. This is a function of global perceptions of the biotech project, but also regulations and policy that affect the long term flow of net benefits (Gravel, 2004). The longer it takes for the approval process to take place, the greater degree of uncertainty for the firm, as it becomes more costly to implement the project. Hence, this first step is ultimately affected by 1. Completion time for regulatory proceedings 2. Sunk costs to enter regulatory process. The best practice partnership addresses the latter of the concerns by holding the public institution accountable for the costs of product and market development in the country of interest. Once a firm attains regulatory approval, it invests with known sunk start-up cost. The uncertainty in this scenario comes with the randomness of project benefits and uncertainty with the irreversibility of the investment process (Gravel, 2004).

Of the various examples of public-private partnership, the “best practice” tends to pool the skills and efforts of partner organizations around *specific* projects with a common objective amongst members of the partnership, employs funding from a philanthropic organization and involves a for-profit partner. Alternatively, partnerships can allow the private company to select amongst a list of pre-selected projects to reduce risks of investments and add value.

Fundamental to these partnerships is creating arrangements where capacity to understand and maneuver intellectual property laws are paramount. Apart from identifying the feasibility of a project and funding sources, the successful partnerships maintain a tight-knit and effective management team that coordinates project selection and ensures overhead costs are minimized without forsaking flexible and responsive organization (Wheeler, C. and Berkley, S, 2001).

The best example of this is the current structure of the Global Alliance for TB Drug Development. It’s mission and focus is *“to accelerate discovery and/or development of cost-effective new TB drugs that will: shorten the duration of TB treatment or otherwise simplify its completion, improve the treatment of latent TB infections and, be effective against multi drug-resistant TB strains.”* The decisive feature of this organization is that they consider patenting and licensing rights a strategic element of project deals. Through past mistakes, ignoring patent law had led to devastating costs and in many cases circumvented by evoking humanitarian goals. However, the new direction involves using patent law to provide a greater incentive for private sector cooperation by selecting profitable projects and encouraging motives for sustainable production.

How can this be accomplished when targeting low-income markets? Companies are compensated for the expected reduced profits in these markets by being allowed to profit from more extensive sales of the product in more profitable markets or allowing for application of the patented technology to other products. These options allow organizations to leverage investments by negotiating to keep profit margins as low as possible. Global Alliance outlines various options for leveraging IPRs for low profits. The similarities between pharmaceutical markets and biotechnology markets include the high cost of the research and development phase, regional specific focus of diseases (crop and human), difficulty of low cost distribution systems and lastly, the need for patent laws to protect the end product. The differences include end-use. Whereas a drug is administered, a hybrid crop or GM product may require training in cultivation methods and techniques. Further, the time between introduction and market adaptation is longer: the process of field testing to specific environments, biosafety and other regulatory processes greatly add to the time between investments and realizing returns on investments. Bar-Ilan and Strange (1996) refer to model of irreversible investments applicable to projects with a "gestation period." Multinationals require a minimum time frame of 8-10 years to develop adapted cultivars to a new market as well as prepare for long-term trial period of success (Maunder, 2000). Lastly, the implications of patent laws are more complex in terms of breeding and marketing in various countries, as we've seen in Section 2.2. These complexities do not preclude the "best practice" relationship, it actually addresses these issues. If a public institution is able use it's own resources for field testing and trial development as well as incorporate it's vast networks for regional testing, in exchange for private sector development and ownership of the final product, the private-public relationship leaves desirability for future investments by addressing some of the risks of the testing process.

Conclusions: Policy Implications for African Seed Development

Agro-industrialization has created added potential for biotech agricultural investments, domestic and foreign, through changing relationships in the food processing and retail sectors by vertical integration. Seed technology progress has lead to food fortification, such as incorporating essential vitamins and micro-nutrients in cereals and has created pest and disease resistant plants that are capable of withstanding harsh environments. Over the last decade, the United States enjoyed tripled investments in agricultural and food R&D, with private sector agricultural spending outpacing that of the public sector. A trend towards vertical integration has resulted between the farmer and the retailer in order to meet increased demands of a middle class with higher purchasing power and ensuring higher quality controls throughout the supply chain.

In the case of Zambia visited in the introduction to this paper, Zambia currently lacks strong public-private partnerships to aid certified seed farmers, suffers from burdensome government involvement in seed trade regulations and lastly, lack of effective managerial and financial expertise in domestic seed companies to facilitate competitive improvements. In addition to institutional deficiencies, seed security is threatened by current Zambian regulations limiting seed donation programs in fear of farmers cultivating plants of unknown varieties that will threaten local genomic land races or counteract with natural pests and, destroy current seed distribution networks (Muliokela, 2004). Hence, the greatest potential impact from investing in the biotech seed industry will occur in economies with the absorptive capacity in terms of infrastructure, regulatory scheme and institutional support.

Kenya provides the perfect example of an emerging economy with an intermediate level of biotechnology, orienting towards a stable seed distribution network which is supporting the shift away from full dependency on the public sector for agri-technology development (Falconi, 1999). Kenya is in the process of establishing a fully functional biosafety regulatory system. The Kenya Agricultural Research institute (KARI) is the leading public institution in agricultural biotechnology and provides the only case in the continental region with field testing success of a hybrid variety. Furthermore, Kenya enjoys a strong public sector for biotech development by hosting the African Agricultural Technology Foundation (AATF), which transfers technology between the public and private sectors to the resource poor farmers. Kenya also houses the Bioscience Center for East and Central Africa and Kenya Agricultural Research Institute which is in collaboration with Monsanto and Syngenta Foundation[5]. It is the collaboration between researchers, extensionists, farmers and policymakers that allows these foundations to prioritize research projects and general development of agricultural biotechnology. In 1996 Kenya formed a biosafety committee and prior to that the Industrial Property Act and Plant Varieties Act was implemented, in an effort to encourage private sector participation (Falconi, 1999). According to

[5]Biotechnology in Kenya is benefits from a special program on Biotechnology

Falconi (1999) there is only one public research organization in the advanced stage of biotech development, whereas the other institutions are in the first stages. Odame et al. (2003) suggests that despite substantial interests by the Kenyan public sector of modern agricultural technologies, the slow progress is evidenced by low-tech applications.

It is recommended that the best way to stimulate foreign investments into African agricultural research is to concentrate on the ability for countries such as Kenya or South Africa to accelerate partnerships with private seed research companies with a specific focus on projects with interregional impact. Public policy should thus facilitate collaborations by:

1. Strengthening intellectual property rights laws that not only protect research conducted within the country, but provisions that protect seeds distribution and marketing as well as clear penalties for violations.
2. Increase administrative resources in regulation and biosafety departments. It is an absolute necessity to decrease the time to wait for a seed company wanting to begin field testing of important crops. The capacity of government departments not only comes in terms of increased staff sizes, but also knowledge of national and international laws
3. Ease research networks between countries by harmonization of biosafety and intellectual property laws.

These policy suggestions hinge on the ability for a private company's perception for success. Intellectual property laws ensure investments are protected, but it also addresses the issue of market structure.

References

Alston, J.M., G.W. Norton, and P.G. Pardey. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca NY: Cornell University Press, 1995.

Bijman, W.J.J. How Biotechnology is changing the structure of the seed industry. Int. J. Biotechnology, Vol. 3, Nos. 1/2, 2001

Brennan, Margret, Carl Prey and David E. Schimmelpfennig. The Impact of Seed Industry Concentration on Innovation: A Study of U.S. Biotech Leaders. Working Paper. Rutgers University.

Brenner, Carliene. 1999. Agricultural Biotechnology in Africa: structural constraints. 1999. Prepared for Workshop on Biotechnology Assessment: Regimes and Experiences in Kenya.

Byerlee, D. and K. Fischer. 2001. Accessing Modern Science: Policy and institutional options for agricultural biotechnology in developing countries. IP Strategy Today No. 1.

Cohen, Joel. 2005. Poorer Nations Turn to publicly developed GM crops. Nature Biotechnology. 23 no.1. 27-33 (2005)

De Greef, W. The Cartagena Protocol and the future of agbiotech. Nature Biotechnolu. 22, 811–812 (2004).

Falconi, Cesar. 1999. Agricultural Biotechnology Research Indicators and Managerial Considerations for four developing countries. Chapter 3 in *Managing Agricultural Biotechnology-Addressing Research Program Needs and Policy Implications.* 1999. CAB International. Ed: J.I Cohen.

Falck-Zepeda, J.B., G. Traxler and R.G. Nelson. 'Surplus Distribution from the Introduction of a Biotechnology Innovation." *Amer. J. Agri. Econ.* 82(May 2000):360-69.

Herring, Ronald. 2003. Underground Seeds: Lessons of India's Bt Cotton Episode for Representations of the Poor, Property Claims and Biosafety Regimes. For the conference, Transgenics and the Poor.

Hall, A. et al. Public-private sector interaction in the Indian agricultural research system: an innovation systems perspective on institutional reform in Agricultural Research in an Era of Privatization (eds. Byerlee, D. & Echeverria, R.G.) 155–176 (CABI International, Wallingford, UK, 2002).

Kameri-Mbote, P., Wafula, D. & Clark, N. Public/Private Partnerships for Biotechnology in Africa. ACTS/Bio- Earn Occasional Paper. (African Center for Technology Studies, Nairobi, Kenya, 2001).

Kellogg, David, John Charnes and Riza Demirer. 2005. Valuation of a Biotechnology Firm: An application of real-options methodologies. University of Kansas working paper.

Khush. Gurdev. 2004. "Biotechnology: Public Private Partnerships and IPR for developing Countries." International Rice Institute. Working Paper.

Khush, G.S. and H. Leung. 2000. Plant genome research and breeding strategies for sustainable food production in the 21st century. Pages 15-27. *In*: L. Esaki (ed.). New frontiers of science and technology. Universal academy press, Tokyo, Japan.

Krattiger, Anatole. Public-Private Partnerships for Efficient Proprietary Biotech Management and Transfer, and Increased Private sector investments. IP Strategy Today. No.4. bio-Developments International Institute. 2002.

Odame, Hannigton, Patricia Kameri-Mbote and David Wufula. 2003. Globalisation and the International Governance for Modern Biotechnology: The implications for food security in Kenya. IERLC 2003 Working paper.

Oehmke, James F. Biotechnology R&D Races, Industry Structure, and Public and Private Sector Research Orientation. AgBioForum æ Volume 4, Number 2 – 2001 – Pages 105-114

Pardey, B. et al. Intellectual property and developing countries: freedom to operate in agricultural biotechnology in Biotechnology and Genetic Resources. (eds. Pardey, P. & Koo, B.) 1–6 (Washington, DC, USA, 2003).

Pigato, Miria. The Foreign Direct Investment Environment in Africa. Africa Region Working Paper Series 15. World Bank. April 2001.

Pray, C.E. D. Ma, J. Huang and F. Qiao. "Impact of Bt Cotton in China" *World Development.* 29 (May 2001):

Pray, C.E. and D. Umali-Deininger. 1998. The private sector in agricultural research systems: will it fill the gap? World Development 26(6):1127-1148.

Spielman, D. & Von Grebmer, K. Public-Private Partnerships in Agricultural Research: an Analysis of Challenges Facing Industry and the Consultative Group on International Agricultural Research EPTD Discussion Paper No.11. (International Food Policy Research Institute, Washington, DC, USA, 2004).

Traxler, Greg, Salvador Godoy-Avila, José Falck-Zepeda, and José de Jesús Espinoza-Arellano. 2002. Transgenic Cotton in Mexico: Economics and Environmental Impacts.

Tripp, Robert. 2003. How to Cultivate a Commercial Seed Sector. Paper prepared for the symposium "Sustainable Agriculture in the Sahel", Bamako, Mali, 1-5 December 2003.

Wambugu, F. 1996. Control of African sweet potato virus disease through biotechnology and technology transfer. Pages 75-81. *In*: J. Komen, J.I. Cohen and O. Zenda (eds.). Turning priorities into feasible programs: Proceedings of a policy seminar on agricultural biotechnology for east and Southern Africa, 23-27 April 1995. The Hague: intermediary biotechnology services/Pretoria: Foundation for Research and Development.

Appendix 1: Tables

Company	Research Area (year)	Contract Value
AgrEvo (GeneLogic)	Disease Resistance (1998)	$ 45 million
Bayer (Arqule)	Library Screening (1999)	$30 million
American Cyanamid (Hyseq)	Genomics (1999)	$60 million

Table 1: World Research Agreements in Agrobiotechnology, 1996-2000 (Echeverria et al, 2001)

Seed Company (country of origin)	2002 Global Seed Sales (US millions)
1. Du Pont/ Pioneer (US)	$2,000
2. Monsanto/Pharmacia (US)	$1,600
3. Syngenta (Switzerland)	$937

4. Seminis (US)	$453
5. Advanta (Netherlands)	$435
6. Group Limagrain (Vilmorin Clause) (France)	$433
7. KWS AG (Germany)	$391
8. Sakata (Japan)	$376
9. Delta & Pine Land (US)	$258
10. Bayer Crop Science (Germany)	$250

Table 2: Top 10 Seed Companies Active in Research and Development (ETC, 2003)

<table>
<tr><th>Crop</th><th>Susbsistence</th><th>Commercial</th><th>Market</th></tr>
<tr><td>Millet</td><td>√</td><td></td><td rowspan="2">Cereal Crops: cultivated in smaller quantities on marginal agro-ecological land for both human and animal consumption</td></tr>
<tr><td>Barley</td><td>√</td><td></td></tr>
<tr><td>Sorghum</td><td>√</td><td></td><td>Cereal Crop: Cultivated in industrial countries as hybrids</td></tr>
<tr><td>Rice</td><td>√</td><td>√</td><td rowspan="2">Cereal Crops: Traded on domestic and international markets, human consumption, animal feed</td></tr>
<tr><td>Wheat</td><td>√</td><td>√</td></tr>
</table>

Maize	√	√	*Cereal Crop:* Cultivated in industrial countries as hybrids; subjected to most private sector R&D expenditure
Cotton		√	*Commercial Crop*: Extensively traded and subjected to major private and public R&D expenditures. Both are OPVs[6]
Soybean		√	

Table 3: A Brief Outline of Cultivation Status of Major African Crops

[6]Open-Pollinated varieties (OPVs) breed true when cross or self-pollinated, i.e. retain the expression of their traits. As a result, when cultivated in isolation farmers can cultivate new varieties by seed-saving

Country	Area of Research
Kenya	Production of disease free plants and micropropagation of pyrethrum, bananas, potatoes, strawberries, sweet potato, citrus, sugar cane Micropropagation of ornamentals (carnation, alstromeria, gerbera, anthurium, leopard orchids) and forest trees *In vitro* selection for salt tolerance in finger millet Transformation of tobacco, tomato and beans Transformation of sweet potato with proteinase inhibitor gene Transformation of sweet potato with Feathery Mottle Virus, Coat protein gene (Monsanto, ISAAA5, USAID6, ABSP7, KARI8) Tissue culture regeneration of papaya *In vitro* long term storage of potato and sweet potato Marker assisted selection in maize for drought tolerance A nd insect resistance Well-established MIRCEN providing microbial biofertilizers in the East African region

South Africa	*Genetic engineering* - Cereals: maize, wheat, barley, sorghum, millet, soybean, lupins, sunflowers, sugarcane - Vegetables and ornamentals: potato, tomato, cucurbits, ornamental bulbs, cassava and sweet potato - Fruits: apricot, strawberry, peach, apple, table grapes, banana *Molecular marker applications* - Diagnostics for pathogen detection - Cultivar identification – potatoes, sweet potato, ornamentals, cereals, cassava - Seed-lot purity testing – cereals - Marker assisted selection in maize, tomato - Markers for disease resistance in wheat, forestry crops *Tissue culture* - Production of disease free plants – potato, sweet potato, cassava, dry beans, banana, ornamental bulbs - Micropropagation of potato, ornamental bulbs, rose rootstocks

Table 4: Research Trends in Selected African Countries (Brink et al, 2001)

Appendix 2: Economic Model

As the structure and depth of influence of the private sector has expanded to support growth in international markets, intellectual property rights and liberalization of the seed markets has begun to account for the specific implications to private industry involvement and it's relevance to the role of local seed companies and public sector institutions. Biotechnology investment decisions are a function of market knowledge size, size of economies in production and recipient country regulations. These elements are also sources of uncertainty and risk for any private sector seed venture. In the end, the ability for private sector development at the local and MNC level is a function of the perceived returns on investment and on shareholder equity. The source of uncertainty can be generalized into two realms: regulatory and technical. Regulatory uncertainty is a result of national and regional policy related to intellectual property and patent rights, seed demand, research infrastructure, as well as the international economic stability. Technical uncertainty is a function of level and ability of vertical integration which affects the ease of research and development of a product and is largely influenced by the presence of other seed companies and NARS (Brennan et al (2001).

Using the best practice scenario developed in Section 3, let us assume an MNC enters into a licensing relationship with a research center in the market of interest (Krattiger, 2002). Of course this is not a risk-less venture, despite having developed the initial research, there are weaknesses associated with possible opportunistic behavior among parties, information asymmetry, general uncertainty on performance of technology in the new market (Bessey et al., 2002). The general risks associated with the limitations on the scope of the patent, possibility of inventing around it and the difficulty of regulation is a function of the general strength of the regulatory framework within the biotech industry (Bessey et al, 2002). The uncertainty hurdle is further compounded by the interest of time: time to wait out the regulatory process and time to build and development. Once time and uncertainty are overcome, a product may reach the market and a firm can realize certain revenues. Until then, however the decision to invest is hastened under uncertainty, where firm would prefer to enter immediately in order to avoid the future opportunity costs (Bar-Ilan and Stange, 1996).

Lavoie and Sheldon (2003) suggests real options as an adequate framework to assess the comparative advantage and dynamic trade relations between biotech investment decisions in the US and Europe. Given the option to invest in the US and EU, Lavoie and Sheldon (2003) found the incentives for private firms to exercise the option to invest in the US was a result of the presence of higher comparative per-period rates of investment and less regulatory uncertainty despite rising R&D costs.

The option to invest is thus subject to various forms of regulatory uncertainty. Gravel et al. (2004) use a simple real options framework to analyze the process of a regulatory review for an investment option in the Ontario electricity market. Similar to a biotech decision, these investments are lagged, irreversible, whose value varies randomly, but the firm must, nonetheless, incur upfront costs to launch the regulatory process (Gravel et al., 2003). Specifically, the probability of success is a direct function of the uncertainty of the regulatory process since it contributes to the delay the decision to initiate the regulatory process and invest in the project.

Following from Bar-Ilan and Stange (1996) and Gravel (2004), the option to start a project can be perceived in terms of the expected net value of the project *V(X)*, itself. The decision to start the project then becomes feasible if the expected net value is 'high enough', i.e. can at the very least recoup the sunk costs of investment at both stages as outlined above. The expectations from the project are subject to the uncertainty of risks associated with regulatory approval and costs of the process. The probability of receiving approval, $q(x) \in (0,1)$ can then be accounted for by a standard normal CDF, $\phi(m,\varpi)$, where for a given realization of *x*, the probability of a positive outcome is a function of 2 parameters (Gravel, 2004).

$$q(x)=\phi\left(\frac{\ln(x)-m}{\varpi}\right)$$

$$\phi_R(x)=V_R(x)=-C_R+q(x)e^{-\rho T_R}\int_o^\infty \phi_P(y,T_R)\,f(y,T_P:x)dy$$

So, the probability of receiving regulatory approval must equal the expected net value of the project at that point:

$$\phi_R(x)=V_R(x)=-C_R+q(x)e^{-\rho T_R}\int_o^\infty \phi_P(y,T_R)\,f(y,T_P:x)dy$$ [7]

[7] It is assumed that the flow of new project benefits follow a geometric Brownian motion and is a lognormal density function:

$$f(y,T_R:x)\equiv\varphi(y:\ln(x)+(\mu-0.5\sigma^2)T_R,\sigma^2T_R)$$
$$\equiv\frac{1}{y\sqrt{2\pi\sigma^2T_R}}\exp\left(\frac{-1}{2}\frac{\left(\ln(y)-(\mu-0.5\sigma^2)T_R)\right)^2}{\sigma^2T_R}\right)$$

$x \in (0, x_R^*)$ Where the net present value during the regulatory process is contingent on

the costs of the regulatory process and the probability of regulatory approval, *q(x)* $\in (0,1)$, and a function of the cumulative probability of success from the investment project, ϕ_P , and time for the regulatory process to be complete, T_R whose risk is adjusted by interest rate, □. Given this, we can say that there exists a value, $x_R{}^*$, for which values below it, would be optimal for a firm to wait before beginning the regulatory process and above would indicate it is beneficial to begin the regulatory process (Gravel, 2004).

Let us assume that $x_R > x_R^*$. It is appropriate to assume that the approval period for the project would last for a limited time, T_A, for which period project uncertainty is subject to changes to the overall socio-economic conditions beyond control of the firm. Also, let T* be the time at which the firm begins the regulatory process. In the deterministic case, the flow of net project benefits is known and the regulatory process will definitely success, *q(x)*=1. Unlike the stochastic problem, the firm knows how X changes and it can immediately make all necessary decisions. Since X moves in GBM, $X(t) = X(0)e^{\mu t}$ and □ is the growth rate of project benefits, the firm's maximization objective function is:

$$e^{-\rho T^*}\left\{-C_R + e^{-\rho T_R}\left[-C_P + e^{-\rho TP}\frac{X(0)e^{\mu(T^*+T_R+T_P)}}{\rho-\mu}\right]\right\}$$

$$e^{-\rho T^*}\left\{-C_R + e^{-\rho T_R}\left[-C_P + e^{-\rho TP}\frac{X(0)e^{\mu(T^*+T_R+T_P)}}{\rho-\mu}\right]\right\}$$

Gravel (2004) solves for T* to be

$$T^* = \frac{1}{\mu}\ln\left(\frac{\rho(C_R + C_B e^{-\rho T_R})}{X(0)e^{-(\rho-\mu)(T_R+T_P)}}\right)$$

$$T^* = \frac{1}{\mu}\ln\left(\frac{\rho(C_R + C_B e^{-\rho T_R})}{X(0)e^{-(\rho-\mu)(T_R+T_P)}}\right)$$

$$x^*_{RO} = \frac{\rho(C_R + C_B e^{-\rho T_R})}{e^{-(\rho-\mu)(T_R+T_P)}}$$

where the numerator the log function is the annualized project cost and the denominator is the value of the flow of project benefits once the projected is completed in the deterministic case. Hence, the value of *X* at which the firm should decide to enter the regulatory process is T*, i.e. when flow of project benefits equal annualized project costs:

$$x^*_{RO} = \frac{\rho(C_R + C_B e^{-\rho T_R})}{e^{-(\rho-\mu)(T_R+T_P)}}$$

Once solving for T*, we can maximize the objective function of the firm to obtain the optimal net profit of the firm:

$$\pi^* = \frac{\mu}{\rho-\mu}\frac{X(0)e^{-(\rho-\mu)(T_R+T_P)}}{\rho}\left[\frac{X(0)}{x^*_{RO}}\right]^{\rho/\mu}$$

$$\pi^* = \frac{\mu}{\rho-\mu}\frac{X(0)e^{-(\rho-\mu)(T_R+T_P)}}{\rho}\left[\frac{X(0)}{x^*_{RO}}\right]^{\rho/\mu}$$

Example of Application

T*: Optimal Time to Begin An Investment Project & Threshold Value of Expected Net Benefits

From our solution for T*, we see that T is an increasing function of costs of regulatory process, costs of project, time for project and interest rates. Intuitively, as the perceived costs of starting and conducting a project increases, a firm would wait longer before starting the regulatory procedures for the investment project since it would reduce the present value of the project. Since the firm incurs sunk costs for both phases of the investment project, a higher interest rate would increase the opportunity cost of the project. Gravel (2004) notes that T* actually first decreases and then increases as the time for completing the regulatory process increases. Since a small increase in the waiting time for regulatory approval has negligible impact of the future discounted net benefits, it doesn't affect the fact that the firm would rather act sooner rather than later. From the objective function we also note that T* is a decreasing function of □, since as the growth of project benefits increase, the firm is likely to invest sooner. The threshold value of the expected net benefits shares similar relationship with T*. □ shares similar relationship as optimal time.

π^* increases with □ and decreases with costs and time.

Analytical Assessment: The Case of Ag-Biotech Investments In Kenya

Following from De Greef (2004), regulatory clearance for developers to market a crop already registered in the main export market is estimated to be between \$7 and \$15 million. The total cost of product development will be estimated at twice this, as De Greef (2004) suggests that the financial burden of regulatory clearance absorbs about half of the total product development investments. A biosafety assessment of a GM crops is estimated between \$0.8 to \$2 million. The best practice model is assumed and for a cash crop, such as cotton. The cotton includes both the small scale, localized farmer and larger, export oriented producer.

Consider the following parameters and range of values for a sensitivity analysis.

α	{0.5,0.66,0.75,0.8}
ω	{0.5,1.00,1.50}
Time for Regulatory approval	{1,2,3,4}
Cost for Compliance	{0.16,.7,2,4}
Duration of Regulatory Approval	{3,5,7,10,25}
Cost for Product Development	{.4,1.75,5,10}
μ	{.01,.02,.044}

The average *per year* regulatory cost per crop is $0.16 million, with almost 75% of the research focus on crop research (Falconi, 1999 and Sithole-Niang et al, 2004). Once the approval process is over, the investor has a limited period of time to act. In the EU, if a crop has been approved for market, the applicant has 10 years to bring the product to market. From time of approval to expiration, developers accrue risks in the product development pipeline. However, as outlined earlier, given the technology's market potential, and general ability to invest significant resources into facilitating technologies through regulatory processes, public research lags and the private industry remains the major source of stimulating a biotech industrial cluster (Sithole-Niang et al., 2004). This would then run in Matlab or similar simulation package that allows the derived probability functions to be programmed.

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