THE GRADUATE INSTITUTE | GENEVA
CENTRE FOR INTERNATIONAL
ENVIRONMENTAL STUDIES

Research Paper 19 | 2013

INNOVATION AND IPRS FOR AGRICULTURAL CROP VARIETIES AS INTERMEDIATE GOODS

D. EATON

Innovation and IPRs for agricultural crop varieties as intermediate goods

Derek Eaton*

May 2013

Abstract

The tradeoffs involved in the extent of appropriability conferred by intellectual property right (IPR) protection to innovators remains an area with many unanswered questions. This paper considers the case of IPRs for product innovations where the product is an intermediate good used to produce a final consumer good. Producers of the final good purchase an innovation from a monopolist, represented in a vertical product differentiation framework. The innovation is subject to an IPR for which the extent of appropriability is determined by a policy maker. The analysis reveals some novel aspects of the traditional innovation versus diffusion tradeoff. More productive producers of the final good benefit from stricter appropriability and the resulting higher level of innovation. Less productive producers, and also consumers, are better off with a moderate level of appropriability. The paper is motivated by the agricultural sector in which an innovator uses genetic resources to produce new crop varieties to be marketed to a farm sector that displays heterogeneity in its ability to profit from the innovation. The scope of the exclusive rights granted over plant varieties has increased in various countries over the past four decades, partly as a result of the TRIPS Agreement, and has been the subject of much policy debate at international, as well as national, levels, partly given potential implications for food security. For these reasons, the model is extended to a two country setting consisting of North and South, which highlights both the interest of the South in maintaining lower levels of appropriability, but also the pressure from farmers in the North for the South to raise its standards. This would not necessarily benefit global consumers.

Keywords: innovation, intellectual property, agriculture, vertical product differentiation, input markets, trade.

JEL classification: Q16; L13; F12

1 Introduction

This paper examines the tradeoffs involved in the scope or strength of intellectual property right (IPR) protection for an intermediate good. Most existing analysis of the level of appropriability consider the case of the scope of IPRs for a final consumption good, or the case of process innovations. The current

*Centre for International Environmental Studies, Graduate Institute, Geneva. Comments and suggestions are gratefully acknowledged from Erwin Bulte, Frank van Tongeren and participants at the 2005 Congress of the European Association of Agricultural Economists (EAAE) and the 2004 Conference of the International Consortium on Agricultural Biotechnology Research (ICABR).

paper develops a simple model involving monopolist innovation and production of a good that is then used to produce a final consumer good. Using a vertical product differentiation model, the amount of innovation in the intermediate good is endogenized and the good can be subject to IPR protection, most likely in the form of patents. The results offer some refinement to the tradeoffs between innovation and diffusion arising from the extent of IPRs seen in the case of consumer goods. Specifically, consumers as a whole may benefit from moderate levels of appropriability if this leads to greater production and lower prices of the final consumption good. An extension to a two country setting with trade highlights the differing interests between countries that are technology producers and those needing to purchase or license.

The motivation for this analysis is the agricultural seed sector, in which IPR protection has been a subject of considerable political controversy. IPR provisions for agricultural plant varieties were developed in industrialized countries during the twentieth century to provide incentives for private sector plant breeders. In most cases, governments opted for plant variety protection (PVP)[1], a specialized form of IPR that is more limited in scope than patents available, for example, for industrial innovations. In general, PVP allows breeders to restrict the commercial production and sale of an improved variety, provided that a number of conditions are satisfied.[2] In some instances, further restrictions may be granted concerning the use of the variety in breeding programs or the use of progeny (second generation seed), but the general lack of such restrictions makes PVP similar to copyright, as much as to patents. In the case of the latter, the use of a patented innovation by others in commercially oriented R&D requires permission of the patent holder. PVP protection, on the other hand, contains a "breeder's exemption" which explicitly allows for the use of protected plant varieties by competitors in their breeding programs.

Industrialized countries introduced their PVP legislation at different stages but most are now members of the International Union for the Protection of New Varieties of Plants (UPOV). UPOV is in effect a treaty which defines specific provisions of PVP legislation which signatories agree to incorporate in their legislation. Two acts of the UPOV treaty exist: UPOV (1978) and UPOV (1991). The 1991 Act increased the scope of protection that members were required to provide, including exclusive rights for the right holder on the import and export of a protected variety. The newer version also requires the possibility of restricting the use of farm-saved seed.[3] The analysis in this paper can be seen as concentrating primarily on restrictions on the use of farm-saved seed or unlicensed commercial sale of a protected variety. This is one of two characteristic, though distinct, appropriability issues in the plant breeding sector. The other is the extent to which competing breeders are permitted or able to use each others innovations in their subsequent breeding efforts (the breeder's exemption). That issue is not addressed in this paper though the literature review discusses relevant papers.

The current paper adds to the existing literature on the farmer's rights (or piracy) issue of appropriability by endogenizing the innovation decision in a vertical product differentiation framework, by explicitly accounting for farm seed as an intermediate good, and by extending the analysis to a two country setting. Considering the innovation good to be an intermediate one used in the production of

[1]Plant varietal protection (PVP) is also referred to by the legal concept of 'plant breeders' rights' (PBR)

[2]These conditions usually comprise the genetic characteristics of Distinctness, Uniformity and Stability, thus DUS(see, for example, Leskien and Flitner, 1997; Ghijsen, 1998).

[3]The 1991 Act does also introduce some possible limitations on the breeder's exemption to address the case "essentially derived varieties" though this has had little impact to date due to difficulties in implementing the associated concept.

a homogeneous final consumer good introduces an interdependence among farms, which can be seen as similar in general nature to network externalities among consumers of competing goods with one important difference. Consumers utility from consuming a good increases with the number of consumers purchasing and using the same good (see, for example, Lambertini and Orsini, 2005). On the other hand, firms purchasing an intermediate good and competing in a final product market benefit from fewer firms competing with them.

2 Literature review

The economic literature on IPRs has evolved from an analysis of a simple discrete case of fully enforceable exclusive rights (Arrow, 1959) to an examination of various dimensions of appropriability provided through either legislation or enforcement and litigation. A general theme in this literature is that of a tradeoff between the dynamic incentives to innovate and the extent of diffusion or benefits enjoyed by consumers (Scotchmer, 2004). One aspect of appropriability that has been analyzed in considerable detail is that of the scope of protection offered, which refers to what is eligible for protection and which activities this protection restricts. Such concepts are elaborated and analyzed by O'Donoghue et al. (1998). This partial equilibrium literature is fairly distinct from general equilibrium approaches, in which the details of IPR policy and implementation must necessarily be simplified. Examples of the latter include Aghion and Howitt (1998); Aghion et al. (2001); O'Donoghue and Zweimuller (2004).

Another literature has examined the incentives and tradeoffs for developing countries to introduce IPR protection, particularly since the negotiation of the TRIPS Agreement. In an earlier general equilibrium setting with homogeneous agents, Helpman (1993) illustrates the channels by which increased IPR protection affects two regions, North and South. In his model, the South has little or no incentive to increase IPR protection if it imitates technological innovations developed in the North, even if this leads to more foreign direct investment and technology transfer. Lai and Qiu (2003) also examine the issue of differential standards in IPR protection between the North and South in a multisector model with homogeneous agents. They find though that there can be net gains to global welfare from a harmonization of the South's level of protection with that of the North, if there are sufficient gains from trade to be earned through associated lowering of the North's import tariffs. This is intended to capture the essence of the bargain made in the Uruguay Round with its inclusion of the TRIPS Agreement; developing countries agreed to this provision as part of a package deal in which greater market access was granted.

The vertical product differentiation model, developed originally by Mussa and Rosen (1978), and further extended by Shaked and Sutton (1982), has also been used to analyze incentives to invest in quality interpreting that as innovation. In a major contribution to this stream of literature, Motta (1993) examined the overall welfare effects of Bertrand vs Cournot competition when the investment in quality is endogenized. Aoki and Prusa (1997) analyzed how the timing of investment affects quality and related this to application process for patents. Extensions of the framework to a multimarket or two country setting and an analysis of trade policy, including technical standards, include papers by van Dijk (1995), Boom (1995), Motta et al. (1997), Cabrales and Motta (2001), Zhou et al. (2002), Toshimitsu (2003), Boccard and Wauthy (2005, 2006), Oladi et al. (2008), and Valletti (2006), who examines monopolist pricing in several market segments defined internationally.

Incorporating the extent of appropriability arising from IPR policy to the vertical product differentiation model arose in the context of copyright protection and piracy of software. Bae and Choi (2006) proposed a model with one innovator and one pirate competing in prices, with the pirate's quality constrained by a parameter reflecting possibly technical limitations to copying the protected product or IPR policy restrictions, including the likelihood of infringement being detected and legal action undertaken. They refine the traditional tradeoff between dynamic and static effects by allowing IPR policy to also affect the cost of copying a protected product which can reduce the dynamic incentives to innovate by reducing the potential market for the monopolist.

More recent papers by Choi et al. (2010) and Belleflamme and Picard (2007) extend the analysis to a duopoly in which two innovators are competing not only against each other, but also pirates. The analysis in the current paper builds on this model of piracy as this represents well the nature of the IP protection issue facing breeders seeking to reduce illegal reproduction of their seed, or similarly policy options to render illegal such reproduction by farmers. Compared to the line of literature based on duopoly models, the single innovator situation changes the competition in quality to a Stackelberg situation. The lower quality producer is constrained to produce a certain quality level (the copy) according to the extent of IP protection, but does not have to invest in developing this.

In a review article in the mid-1990s, Lesser (1997) indicated that there had been relatively few attempts to model PBRs as an explicit form of IPR. The subsequent expansion in the diffusion of genetically modified crops and increasing relevance of patent protection for the breeding sector, in addition to PVP, has stimulated further theoretical development in the literature. The vertical product differentiation model has recently been applied to the agricultural plant breeding and biotechnology sector by Fulton and Giannakas (2004), Plastina and Giannakas (2007), Giannakas and Yiannaka (2008). These papers have analyzed the market and welfare effects of the introduction of genetically modified crops, including the effects of segregation and labeling policies, but have not endogenized the decision to invest in quality. This issue has been formally analyzed by Moschini and Lapan (1997). Yerokhin and Moschini (2008) develop a duopoly R&D model of plant breeding to examine the effects of the breeder's exemption on strategic behavior between two innovators. Alston and Venner (2002) do incorporate partial appropriability into their model developed for U.S. PVP situation, but do not include competition from other sources of seed or the interdependence between farms producing for a final output market. Van Tongeren and Eaton (2004) extended the model of Alston and Venner (2002) to a two country setting, illustrating that lower appropriability in a second weaker market could be welfare enhancing due to the benefits of third degree price discrimination.

Heisey and Brennan (1991) developed a model of incentives at the (representative) farm level to purchase seed more frequently rather than to produce seed from last year's existing crop. They did not however consider the effect of possible legal restrictions on such activity, as their analysis was motivated by the productivity benefits of diffusing modern varieties to farmers in developing countries.

A paper that is similar in aim to the current one is by Burton et al. (2005). They develop a model to analyze the competition that breeders face from piracy and compare legal protection options in the form of contracts with farmers to technical protection in the form of genetic modification that prevents plant from producing fertile seeds.[4] Ambec et al. (2008) also examine the incentives to reduce the

[4] Such technologies, which have yet to be developed to commercial viability, are generally known as genetic use restriction technologies (GURTs).

reproducibility of seed (a form of durable good) but do not address the incentive to invest in innovation.

3 Model

3.1 An intermediate good with a monopoly innovator

The analysis is based on a simple model of vertical product differentiation, but in which farms instead of consumers are differentiated. The vertical product differentiation model is typically applied to situations where final consumption goods differ in some quality attribute which affect consumers utility. The framework can also plausibly be extended to the situation of intermediate production goods. In the analysis presented here, this good is seed (or planting material) that is sold to farmers. This difference can be interpreted as their varying capacity of farmers to profit from higher quality seed, which can be due to a range of physical and human factors, including differences in agro-ecosystems and quality of land resources, farmers' knowledge and technical capabilities, or access to financial and physical capital. The agricultural sector lends itself to this interpretation as it is generally composed of a large number of small, heterogeneous firms (farms), producing relatively homogeneous products in a competitive setting.

Farms are distributed uniformly along a continuum $[0, \bar{\theta}]$.[5] It is assumed that each farmer purchases one unit of the seed if positive profits can be earned, $g\theta u - p > 0$, where u and p are, respectively, the quality level and price of the seed and g is the price earned for farm output. If net farm profits are zero or less, the farm purchases no seed, and does not produce.

The innovator/seed producer make two profit-maximizing decisions sequentially.[6] First, they must choose a level of quality u, with an associated cost function of $C(u)$. Secondly, the seed producer sets the price, p. The choice of quality level is often interpreted as an R&D investment decision (Motta, 1993). The analysis here assumes in the first instance a simple quadratic function, $ru^2/2$, with r a scaling factor. For simplicity, production costs of seed are assumed to be zero, as interest focuses on the investment decision.

The simplest version of the model examines the situation of a monopolist innovator, (denoted with subscript 1), who faces competition from "piracy", unauthorized production and sale of its product, indexed by c. The pirated seed differs in quality from the original according to a parameter $\delta \in (0, 1)$. As $\delta \to 0$ then the pirated seed does not differ from the original at all, and at the other extreme as $\delta \to 1$, the copied seed would effectively be of zero quality. We interpret δ as a measure of appropriability of the research innovations embodied in the quality of the seed. In particular, the degree of appropriability represents a constraint, due to the (partial) granting or enforcement of intellectual property rights, on the ability of the pirate to reproduce the same plant variety or to charge the same price. These IPRs could include plant breeder's rights, or also patent, trademark or trade secret protection. In addition to the legal interpretation, appropriability could reflect biological/technical factors which result in deterioration in the quality of the reproduced seed. This is quite common in the case of hybrid seeds,

[5] Some earlier versions of the vertical product differentiation model assumed that the market was completely covered; Wauthy (1996) has generalized this class of models to allow for endogenous determination of market coverage. Note that Bae and Choi (2006) do not assume a specific distribution, which is a potential generalization discussed below in the conclusions.

[6] The sequential nature is not necessary in the first analysis of the model but is introduced now as it will be used in the extension to a two country setting.

the progeny of which farmers may try to save and replant, a practice quite common in many developing countries. But even in the case of open-pollinated varieties (OPV), there may be a loss of quality in copies or subsequent generation seed due for example to fewer efforts devoted to sorting and treating seed.

Each farm (indexed by θ) chooses between purchasing the bona fide seed with quality u at price p_1, or the copy with quality $(1-\delta)u$ at a constant price c, with profits respectively of $g\theta u - p_1$ and $g\theta(1-\delta)u - c$. Note that the copied seed could also be produced by the farm itself, which would also require the use of farm resources or can be thought of as the opportunity cost of not selling such seed to other farms. There are therefore effectively no barriers to producing the copied seed and thus no profits to be made.[7]

The solution method proceeds backwards by first solving for price and then the quality investment decision of the monopolist seed producer. To solve the price decision, denote by θ_1 the farm which is indifferent between purchasing the original seed from the monopolist and the pirated seed, which implies that $g\theta_1 u - p_1 = g\theta_1(1-\delta)u - c$, or $\theta_1 = (p_1 - c)/g\delta u$. The range of farms choosing for the monopolist's seed, $(\bar{\theta} - \theta_1)$, increases with lower prices (p_1), with higher prices for copied seed (c), for higher values of the output price (g), higher levels of quality of the seed (u), or higher levels of appropriability of the benefits of innovation (δ). Similarly, the farm which is indifferent between purchasing lower quality pirated seed and not producing at all, denoted by θ_c, is found by solving $g\theta_c(1-\delta)u - c = 0$, or $\theta_c = c/(1-\delta)gu$. The range of farms choosing pirated seed, $(\theta_1 - \theta_c)$, decreases with increases in the price of this seed (c), but the relationship with output price and quality depends on the interaction in the pricing decisions of the monopolist and the pirate(s). Higher levels of appropriability (δ) will however also decrease the range of farms choosing pirated seed, by raising θ_c in addition to lowering θ_1.

Recalling that each farm produces one unit of output, total supply in the final goods market is simply the number of farms producing, given by $(\bar{\theta} - \theta_c)S$, where S is the mass of farms.[8] Demand is assumed to be unitary elastic: b/g. Substituting in the expression above for θ_c, and equilibrating demand and supply leads to the following solution for farm product price g:

$$\frac{b}{g} = S\left[\bar{\theta} - \frac{c}{(1-\delta)gu}\right], \text{ or}$$

$$g = \frac{b(1-\delta)u + Sc}{S\bar{\theta}(1-\delta)u}. \tag{1}$$

Expressions for the indifferent farms, θ_1, θ_c, can then be derived substituting for g:

$$\theta_1 = \frac{S\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}, \quad \theta_c = \frac{S\bar{\theta}c}{[b(1-\delta)u + Sc]}. \tag{2}$$

[7] This differs from most other models of piracy in the production of consumer goods, which assume certain barriers to piracy and thus prices for the pirated good that may exceed marginal cost (as in Bai and Choi 2006).

[8] Although S is not essential for deriving the results for a single country, we introduce it now as it will play a more important role in the context of two countries.

Total quantity of monopolist seed and pirated seed can then be derived in terms of p_1:

$$q_1 = S(\bar{\theta} - \theta_1) = S\bar{\theta} - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}$$

$$q_c = S(\theta_1 - \theta_c) = \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]} - \frac{S^2\bar{\theta}c}{[b(1-\delta)u + Sc]}.$$

Given a quality level, u, the monopolist set its price to maximize profits, taking into account effects in the final good market. Note that the monopolist also incurs the same cost of producing seed, c:

$$\begin{aligned}\Pi_1 &= (p_1 - c)q_1 = (p_1 - c)\left[S\bar{\theta} - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]}\right] \\ &= S\bar{\theta}(p_1 - c) - \frac{S^2\bar{\theta}(1-\delta)(p_1 - c)^2}{\delta[b(1-\delta)u + Sc]}\end{aligned}$$

Maximizing Π_1 with respect to p_1 implies

$$S\bar{\theta} = \frac{2S^2\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]} \Rightarrow p_1 = \frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)} + c \tag{3}$$

which expresses p_1 as the monopolist's production cost plus a markup, which corresponds to $\delta g u\bar{\theta}/2$. Note that p_1 charged by the monopolist increases with both higher quality, u, and greater appropriability, δ, which is intuitive. This leads to the following solutions for θ_1, q_1:

$$\begin{aligned}\theta_1 &= \frac{S\bar{\theta}(1-\delta)(p_1 - c)}{\delta[b(1-\delta)u + Sc]} \\ &= \frac{S\bar{\theta}(1-\delta)}{\delta[b(1-\delta)u + Sc]} \cdot \left[\frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)}\right] \\ &= \frac{\bar{\theta}}{2} \\ q_1 &= S(\bar{\theta} - \theta_1) \\ &= S\frac{\bar{\theta}}{2}.\end{aligned} \tag{4}$$

The finding that the monopolist will serve a fixed portion of the market, in absence of competition, is found in the original result by Mussa and Rosen (1978). This relatively simple structure of the model also means that the proportion of the market served by copied seed, is also not dependent on the monopolist's price:

$$\begin{aligned}q_c &= S(\theta_1 - \theta_c) \\ &= S\left[\frac{\bar{\theta}}{2} - \frac{S\bar{\theta}c}{[b(1-\delta)u + Sc]}\right] \\ &= S\left[\frac{\bar{\theta}[b(1-\delta)u + Sc] - 2S\bar{\theta}c}{2[b(1-\delta)u + Sc]}\right] \\ &= \frac{S\bar{\theta}}{2}\left[\frac{[b(1-\delta)u - Sc]}{[b(1-\delta)u + Sc]}\right]\end{aligned}$$

Proposition 1: The level of quality offered and the profits earned by the monopolist are maximized *with a maximum level of appropriability.*

The monopolist's decision to invest in quality is solved by maximizing the full profit function with respect to u, including the cost r of investment in addition to profits from selling seed is

$$\begin{aligned}
\pi_1 &= (p_1 - c)q_1 - \frac{ru^2}{2} \\
&= \frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)} \cdot S\frac{\bar{\theta}}{2} - \frac{ru^2}{2} \\
&= \frac{\delta\bar{\theta}}{4}\left(bu + \frac{Sc}{1-\delta}\right) - \frac{ru^2}{2} \qquad (5)
\end{aligned}$$

$$\frac{\partial \pi_1}{\partial u} = 0 \ \Rightarrow u = \frac{\delta\bar{\theta}b}{4r}. \qquad (6)$$

The monopolist's price can then be rewritten as

$$\begin{aligned}
p_1 &= \frac{\delta[b(1-\delta)u + Sc]}{2S(1-\delta)} \\
&= \frac{\delta c}{2(1-\delta)} + \frac{\delta^2 b^2 \bar{\theta}}{8Sr} + c\,. \qquad (7)
\end{aligned}$$

Thus as intuition would suggest, the level of quality (or innovation) increases with the strength of final demand (b) and also appropriability (δ), but decreases with the cost of innovation (r). Quality is not directly determined by the cost of producing or copying. Substituting this solution back into the monopolist's full profit function, we find that

$$\pi_1 = \frac{\delta^2\bar{\theta}^2 b^2}{32r} + \frac{\bar{\theta}Sc}{4(1-\delta)}$$

and so profits are increasing in δ, as might be expected.

Proposition 2: Total profits of farms purchasing from the monopolist are maximized with maximum appropriability.

This is proven by maximizing the expression for profits for these farms with respect to δ, which always occurs at the maximal value of $\delta = 1$ (see 5). The simple intuition is that maximum appropriability effectively eliminates competition for farms in the final product market from those farms producing copied seed. Higher appropriability allows the monopolist to charge a higher price for the seed, but farms are able to pass on these increases given the perfectly elastic demand specified for the product market. As noted above, one feature of this specification is that the proportion of farms purchasing the monopolist's seed remains constant. In markets with a limit price for the final good, then a decreasing proportion of farms would find it profitable to produce as the price of the input keeps rising. For now, we note that this stylized situation can be interpreted as representing the agricultural sector as a whole, as opposed to a single sector, with demand for food output being relatively inelastic over the long term.

Proposition 3: Profits for farms using copied seed could be maximized at the moderate level of appropriability $\delta = 1/2$ provided the strength of demand for the farm's product sufficiently exceeds the cost of producing seed.

The proof is found in the 5 and is also obtained by maximizing the respective expression for total farm profits. The result of $\delta = 1/2$ is obtained provided that the strength of demand for the final product is sufficiently larger, in relative terms, than the cost of producing and copying seed, which seems acceptable. As a whole, farms using copied seed do not therefore achieve maximum total profits with no appropriability at all ($\delta = 0$), since there is then no incentive for the innovator to invest in quality. At very low levels of appropriability, the quality is so low that very few farms are able to produce profitably using copied seed. Further increases in appropriability at this low level, only partially offset the ability of farms to use this seed. However once appropriability has reached a higher level, it dominates the increases in quality that it stimulates, and the number of farms being able to produce profitably with copied seed starts to decline. As shown in the Annex, the range of values for δ, centered around $\delta = 1/2$, for which total profits exceed those at minimum or maximum appropriability rises as the ratio between final demand and cost of the input increases.

Proposition 4: Consumers benefit most from a moderate level of appropriability, set at $\delta = 1/2$.

The proof is found in 5.3 and is obtained by minimizing the expression for consumer's price, g, with respect to δ (after substituting for u, using (6)):

$$g = \frac{b}{S\bar{\theta}} + \frac{4cr}{\delta(1-\delta)b\bar{\theta}^2}\,. \tag{8}$$

Thus consumers also benefit most from having a moderate level of appropriability. This is a static view though based on the price for the consumer good, in this case food that is characterized as an essential good with an infinitely elastic demand. A moderate level of appropriability maximizes farm production. In this model, this requires that as many farms are able to use or purchase copied seed, since the number of farms using seed purchased from the monopolist is fixed ($\bar{\theta}/2$) and thus production from those farms is also fixed. This does not correspond to a maximum level of appropriability which maximizes innovation or investment in quality (as can be seen from (6)). As appropriability increases beyond moderate levels, the increased investment in quality is not available to as many farms using copied seed, and only results in increased profits for farms purchasing seed, not in increased production. This reflects the assumptions of the model: each farm produces either one unit of final product or not at all, and also the parametrization of the demand function for farm product. If quality of seed led to greater farm output, then increased appropriability, and thus quality, might also benefit consumers. Nonetheless, this model illustrates how there can be a tradeoff between quality and consumer welfare. It is also worth pointing out that, while this model represents essentially a static situation, a dynamic perspective might also suggest that consumers would benefit in the long run from greater innovation.

The analysis highlights how the decision for policy makers setting the level of appropriability can involve tradeoffs, particularly as there may be multiple policy objectives. In terms of social welfare, as measured by profits of the monopolist and farms, in addition to consumer's surplus, the optimal level of appropriability would be somewhere between the moderate level ($\delta = 1/2$) that most benefits consumers and also farms using copied seed, and the maximum level ($\delta \to 1$) that most benefits the monopolist and its client farms. In terms of the agricultural setting considered in this analysis, a moderate level of appropriability could also be the optimal policy from a food security perspective, as it ensures the lowest price for food. If though policy takes an agricultural sector perspective and seeks to maximize profits in the sector, the optimal level of appropriability would be the maximum available. On the other hand, policy also needs to take account of differential effects among farms by seeking to ensure profitability for less well-endowed or productive farm businesses (perhaps from a social equity perspective), then a more moderate level of appropriability would again be favored.

In general, these features of the model capture the essential characteristics of the agricultural and plant breeding sector in recent decades. Through revisions to UPOV (1991 Act, as well as ongoing discussions among UPOV members and the breeding industry) and also increasing applicability in different jurisdictions of patent protection for plant varieties, or the biotechnological constructs contained in them, appropriability has been increasing. This has revealed differing interests among farms, with those generally most able to profit from improved innovations being supportive. But other farmers have voiced opposition and also committed acts of infringement on the use of protected seeds. Consumers have not been as active in this debates and discussions, except with regards to the introduction of genetically modified crops. For consumers as a whole, any resulting improvements in productivity of agricultural production have not necessarily translated into reduced prices for food products.[9] So consumers are arguably not yet appreciating any benefits of possibly accelerated innovation resulting from higher appropriability. It could be argued that more time is needed for these incentives to influence research and development in plant breeding, and to result in commercialized products. But the consumer perspective is complicated. Many consumers are suspicious of possible health and environmental risks associated with genetic modification. Interestingly though, many appear also to have ethical concerns related to increasing levels of appropriability - concerns that are not related to possible price effects. It should also be noted that any price effects may be difficult to discern given larger trends in the past two decades towards increasing prices for basic foodstuffs, driven largely at a global level by growing demand from emerging economies (see, for example, Koning and Mol, 2009).

3.2 Extension to two countries

The analysis is now extended to a situation involving two countries. It is assumed that innovation takes place in the North (N) and that now the monopolist can also market this in the South (S), but must also compete against unauthorized copying and sale of the seed. First the relatively simple situation of autarky is considered, in which there is no trade in the farm product, and then it is seen how the solutions will change if international trade in the farm product also takes place.

In general, due to lower incomes, the strength of demand for the final farm product is expected to be lower in the South than in the North: $b_S < b_N$. In terms of the farm sector, the South is assumed to consist of a larger mass of farms ($S_S > S_N$). Although the most productive farm in the South, indexed by $\bar{\theta}_S$, could be more or less productive than that of the North ($\bar{\theta}_S \lesseqgtr \bar{\theta}_N$), in general the analysis restricts itself for reasons of simplicity to considering that the distributions are identical. The monopolist is based in the North.

The analysis is relatively short-term in that the level of innovation, as represented by u, is taken as exogenous to the opening of trade in either seeds or the final product. It would be expected that the opportunity to serve the market in the South would, in time, influence the decision by the monopolist innovator as to the amount of investment and thus the level of quality. Introducing this longer term consideration would entail multiple equilibria (indeed an infinite number given the continuous nature of the decision to invest in quality).

[9] Note though that in developed countries, the production price of agricultural crops is a small proportion of the final consumer price of food staples, with transport, processing and marketing generally accounting for a larger share.

Regarding sequencing of policy decisions, the North first determines its own level of appropriability through IPR policy (δ_N) in both cases. The South takes this as given and then determines its own level of appropriability (δ_S). This can be considered as representing a situation prior to TRIPS. Then the situation is examined in which the South is required, by international agreement, to raise its level of appropriability with that of the North. This could be due to multilateral agreements such as TRIPS, or regional or bilateral trade agreements. As with the Uruguay Round and the creation of both the WTO and TRIPS, this represents a negotiated outcome in which the South hopes to gain increased access to markets of the North, but must agree to TRIPS as part of the overall deal. Together with the assumption that the innovator bases its investment decision only on the market in the North, the analysis below can best be seen as representing the post-TRIPS short-run situation. This is not to argue that the longer term effects are not as important, if not more so; however, the insights generated are relevant for explaining the policy and public debates that have taken place around the adoption of TRIPS.

3.2.1 Autarky in the final product

In the simplest situation, the North determines its own level of appropriability as above, which leads to decisions by the monopolist for innovation in quality as seen in the previous analysis. The South then takes the level of quality, u, as given and determines its own level of appropriability, δ_S, where the subscript S now denotes the South. Starting with the final product market, equilibrium is characterized as in (8):

$$g_S = \frac{b_S(1-\delta_S)u + S_S p_{cS}}{S_S\bar{\theta}_S(1-\delta_S)u} \,. \tag{9}$$

where

$$u = \frac{\delta_N\bar{\theta}_N b_N}{4r}, \tag{10}$$

inserting subscripts N for North (except for the cost of investing in quality, r for which there is only one value).[10] Then the price in the South and the North can be written as follows:

$$\begin{aligned} g_S &= \frac{b_S}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)u} = \frac{b_S}{S_S\bar{\theta}_S} + \frac{4cr}{\delta_N(1-\delta_S)b_N\bar{\theta}_S\bar{\theta}_N} \\ g_N &= \frac{b_N}{S_N\bar{\theta}_N} + \frac{c}{\bar{\theta}_N(1-\delta_N)u} = \frac{b_N}{S_N\bar{\theta}_N} + \frac{4cr}{\delta_N(1-\delta_N)b_N\bar{\theta}_N^2} \,. \end{aligned}$$

From this it can be seen that if demand is weaker in the South ($b_S < b_N$) and if appropriability in the South is no stronger than that of the North ($\delta_S \leq \delta_N$), then the price of the final product will be lower in the South ($g_S < g_N$).

The monopolist incorporates the final product price into the determination of its seed price:

$$p_{1S} = \frac{\delta_S[b_S(1-\delta_S)u + S_S c]}{2S_S(1-\delta_S)} + c \tag{11}$$

and thus undertakes price discrimination between the northern and southern markets. As in the initial

[10] Since u is determined entirely by the circumstances in the North, in some of the derivations below, it is maintained as a variable for ease of interpretation.

analysis above, the values for the cutoff farms, defining the size of the monopolist's market and the market for copied seed, respectively are:

$$\theta_{1S} = \frac{\bar{\theta}_S}{2} \text{ and } \theta_{cS} = \frac{S_S\bar{\theta}_S c}{[b_S(1-\delta_S)u + S_S c]}\ .$$

Note that this model does not predict that monopolist will increase export of seeds to South as the latter increases its appropriability. This is due to the specification of the model with a fixed share of the market served by the monopolist. It is possible to conceive that the market in South is served only by traditional seed varieties prior to the monopolist entering the market, which also leads to the availability of seed copies. This is however clearly unsatisfactory and it would be preferable if the share of the market in the South, given a fixed quality, were directly related to the level of appropriability available; in other words that θ_{1S} were decreasing in δ_S. Again, this arises from the assumption of fixed output per farm and the specification of an infinitely elastic demand for the final product. Nonetheless we proceed to examine how the interests of different actors (monopolist, farms and consumers) are related to the level of appropriability offered.

Proposition 5: The additional profits for the monopolist from marketing seed in the South are maximized with a maximum level of appropriability feasible.

As in the single country case, the monopolist profits from selling additional seed in the South (see (5)),

$$\pi_{1S} = \frac{\delta_S\bar{\theta}_S}{4}\left(b_S u + \frac{S_S c}{1-\delta_S}\right)$$

can be easily seen to be increasing in δ_S.

Proposition 6: Total profits of farms in the South purchasing the monopolist's seed are maximized with a maximum level of appropriability that is feasible.

The proof is given in 5.4. The intuition is that maximal appropriability allows these farmers purchasing the monopolist's seed to capture all of the market in the South, and they are still able to pass on high prices they pay to the monopolist for seed to the consumer in the form of a higher price for farm product.

Proposition 7: Under autarky, total profits for farms in the South using copied seed will be maximized with a minimal level of appropriability if the strength of demand sufficiently exceeds the cost of producing seed.

The results is shown in 5.5. As in the situation for the North, this means that if the strength of demand is sufficiently strong relative to the cost of producing seed, then the total profits earned by farms using copied seed will be maximized with little or no appropriability. Note also that this implies maximum diffusion of the innovation, in the form of copied seed, in the South. Otherwise, profits will be maximized at a maximal level of appropriability, and somewhat counter-intuitively, enjoyed by a very limited number of farms.

Proposition 8: Under autarky, consumers in the South benefit from a minimal level of appropriability.

Recalling (8), the price for consumers in the South is simply

$$g_S = \frac{b_S}{S_S\bar{\theta}_S} + \frac{c}{(1-\delta_S)u} \tag{12}$$

and ${}^{\mathrm{d}g_S}/_{\mathrm{d}\delta_S} > 0$; so price in the South is minimized with $\delta_S \to 0$. The lowest level of appropriability maximizes the number of farmers producing in the South (θ_{cS} is also increasing in δ_S; see (2)) and thus the price of farm output.

In summary, under autarky there are different interests in the second country concerning the level of IPR protection that are somewhat similar to those in the single country case. The monopolist and the most productive farms benefit from maximal levels of appropriability. Less productive farms, on the other hand, could benefit most from a minimal level of productivity, under conditions of sufficiently strong demand for farm product relative to costs, which would also maximize the diffusion of the innovative seed. For this reason, consumers would also benefit most from minimal appropriability, and thus have interests essentially opposite to those of the monopolist and the more productive farms. This corresponds to restricting attention to the static situation examined in the single country case, where the effect of appropriability on innovation is ignored. It has here been assumed that the monopolist has based the investment decision only on the market situation in the North, and is now marketing this product in the South. Under these circumstances, if the South initially has a minimal level of appropriability, then any increase, as induced say by implementation of TRIPS, serves to increase the profits of the Northern monopolist but also the most productive part of the farm sector. On the other hand, consumers would be penalized through higher prices. Agreements on IPR protection, such as TRIPS, are also generally accompanied by measures to liberalize trade, as in the Uruguay Accord establishing the WTO in general, and the analysis now turns to how trade might affect these results.

3.2.2 Trade in the final product

The assumptions of the previous section concerning the weaker demand in the South ($b_S < b_N$), but with a larger mass of producers ($S_S > S_N$), are maintained.[11] When trade takes place in the final product, then its price will converge between North and South, leading to a new world price, g_W with $g_S < g_W < g_N$ and where

$$g_W = \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{u}\left(\frac{1}{1-\delta_N} + \frac{1}{1-\delta_S}\right)\right] . \tag{13}$$

If the situation is still as in the previous section under autarky, with u fixed, then the only way that production can adjust to trade is for it to decrease in the North and to increase in the South. Given the assumptions and specification of the model, this implies that θ_{cN} increases, while θ_{cS} increases (as confirmed below), and so the change in production is undertaken by a reduction in the North of the number of farms producing with copied seed, and an increase of such farms in the South.

Proposition 9: Given weaker final product demand and/or a larger mass of farms in the South relative to the North, opening to trade in the final product market will decrease the profits of farms in the North producing with purchased seed and increase the profits of such farms in the South.

From 15, profits for farms producing with purchased seed can be derived more simply, maintaining

[11] And $\bar{\theta}_S = \bar{\theta}_N$.

g_i, $(i = N,\, S)$ as follows:

$$\begin{aligned}
\tau_{1i} &= \int_{\theta_{1i}}^{\bar{\theta}_i} (g_i \theta u - p_{1i})\, \mathrm{d}\theta \\
&= \left[\frac{g_i u}{2}\theta^2 - p_{1i}\theta\right]_{\theta_{1i}}^{\bar{\theta}_i} \\
&= \frac{g_i u}{2}\left[\bar{\theta}_i^2 - \frac{\bar{\theta}_i^2}{4}\right] - p_{1i}\frac{\bar{\theta}_1}{2} \\
&= \frac{3}{8} g_i u \bar{\theta}_i^2 - \frac{1}{4} g_i \delta_i u \bar{\theta}_i - \frac{c}{2} \\
&= \frac{g_i u \bar{\theta}_i}{4}\left(\frac{3}{2}\bar{\theta}_i - \delta_i\right) - \frac{c}{2}\,. \qquad (14)
\end{aligned}$$

This is increasing in g. So if g_N decreases in the opening to trade to g_W, then τ_{1N} decreases. Similarly, if g_S increases to g_W, then τ_{1N} increases.[12]

Proposition 10: Given weaker final product demand and/or a larger mass of farms in the South, opening to trade in the final product market will lead to lower overall profits for farms in the North producing with copied seed, and higher overall profits for such farms in the South, provided that the strength of demand in each market is sufficiently strong relative to the cost of producing seed.

The proof in 5.6 shows that if the strength of demand sufficiently exceeds the cost of producing seed, then the profits of farms using copied seed increase in final product demand. So if trade leads to a world price, g_W, lower than the price in the North under autarky, g_N, then farms using copied seed in the North lose from trade, and conversely for farms in the South using copied seed.

The analysis indicates that opening to trade in the final good could increase the political pressure from the agricultural sector in the North on the South for the latter to strengthen its IPR protection. In terms of the different interest groups in the North, this would clearly benefit the monopolist, and it would also be in the interests of farms in the North, including those purchasing seed as well as those using copied seed. An increase in appropriability in the South would partly redress the losses of farms in the North from the opening of trade, by reducing production in the South and thus increasing the world price for the farm product. To see that production in the South would be reduced, recall that, under trade, production in the South is determined by

$$\theta_{cS} = \frac{c}{(1-\delta_S) g_W u} \text{ and}$$

$$\begin{aligned}
\frac{\partial \theta_{cS}}{\partial \delta_S} &= \frac{c}{u}\left(\frac{1}{(1-\delta_S)^2 g_W} - \frac{\partial g_W / \partial \delta_S}{(1-\delta_S) g_W^2}\right) \\
&= \frac{c}{(1-\delta_S) g_W u}\left(\frac{1}{(1-\delta_S)} - \frac{\partial g_W / \partial \delta_S}{g_W}\right)\,.
\end{aligned}$$

[12] Note that in 14 we see δ is negatively related to farm profits, which seems counter-intuitive to the result above that increased appropriability increases farm profits (for those purchasing seed). As g_i is being kept in the derivation, δ_i reflects only the effect of increased appropriability on higher prices that the farms must pay for purchasing seed. But this is easily passed on to consumers in the specification of final demand chosen here. Farms end up benefiting more through the effects of higher appropriability on g_i. This does indicate though that the results do depend considerably on the nature of the demand function chosen.

The sign of this derivative is determined by

$$
\begin{aligned}
& g_W - (1-\delta_S)\frac{\partial g_W}{\partial \delta_S} \\
= \; & g_W - \frac{c}{(S_N\bar{\theta}_N + S_S\bar{\theta}_S)(1-\delta_S)u} \\
= \; & \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{u}\left(\frac{1}{1-\delta_N} + \frac{1}{1-\delta_S}\right)\right] - \frac{c}{u(S_N\bar{\theta}_N + S_S\bar{\theta}_S)}\left(\frac{1}{1-\delta_S}\right) \\
= \; & \frac{1}{S_N\bar{\theta}_N + S_S\bar{\theta}_S}\left[b_N + b_S + \frac{c}{(1-\delta_N)u}\right] \\
> \; & 0 \, .
\end{aligned}
$$

So $\partial\theta_{cS}/\partial\delta_S > 0$ and thus an increase in appropriability in the South, following on the opening of trade, will always reduce the number of farms in the South producing with copied seed, thus reducing production. On the other hand, farms in the South purchasing the monopolist's seed will benefit from higher appropriability through the higher global price, as was shown above under the autarky situation, even though they will have to pay a higher seed price. Consumers in both the North and the South will though have to pay a higher price and will therefore not be in favor of increasing appropriability in the South.

These differing interests in IPR policy in the model correspond to what has been witnessed with the introduction of TRIPS in the agricultural sector. Resistance or opposition to implementing TRIPS obligations in Article 27(3)b has come from small-scale farmers concerned about their access to seeds and being able to continue producing. Many governments in the South have expressed concern that food security could be negatively affected, both among the smallholder farm sector, but also on urban consumers through lower production and higher prices. There has been support though from more productive and modernized segments of the farm sector who can benefit from improved access to technology and international markets. The analysis here suggests that such farmers may also see pecuniary benefits from reducing competing production from farms using copied or imitation seed. Perhaps for similar reasons, farm businesses in the North have also lobbied their own governments to exercise pressure on developing countries to implement TRIPS obligations and increase appropriability. On the other hand, consumer groups and NGOs in developed countries have, if anything, expressed concern about the potential effects on food prices and food security. This analysis remains however essentially static by not considering the effects on the incentive to innovate in the future. Such extensions are discussed below in the concluding section.

4 Conclusions

The analysis has elaborated a simple model of innovation in the production of an intermediate product to examine the effects of different levels of appropriability enacted through an IPR system. The model accounts for heterogeneity among producers of the final good, with agricultural production and the use of planting material as the motivating context. Beginning with a single country setting, while a monopolist innovator benefits most from maximum appropriability, the intermediate producers (farms) have differing interests. The more productive among them, or those best placed to profit from an improved variety, will benefit from the greater level of innovation that maximum appropriability would encourage the monopolist to provide. The less productive though, may benefit from a more moderate level of appropriability if this allows a greater number of them access to the seed of the improved variety, possibly even through illicit ("pirated") copies. As the final food product is homogeneous and unaffected by the level of innovation, consumers benefit from maximum production, which implies a moderate level of appropriability. If appropriability were too low, then the resulting decline in the level of innovation and quality of the seed, would have a negative effect on production, as fewer farms would find it profitable to produce.

The results of the analysis here for the level of farm production are similar to what has been obtained in recent literature on the piracy of copyrighted ICT technologies, although in that case, consumers correspond to farms, or the intermediate producers. The addition of the extra level of production introduces an interdependence between intermediate goods producers, and also highlights a novel dimension of the traditional innovation-diffusion tradeoff. The aggregate interest of the farm sector is most closely aligned to that of the monopolist, in preferring maximum appropriability and innovation. But there is a minority of farms that do not benefit and are excluded from producing, and their interests lie closer to those of consumers, who benefit from greater production and lower prices. This can help explain the political alliance between farm groups representing more "marginal" farms and also consumer's associations in general opposition to stronger IPRs for the plant breeding sector. Opposition from consumers to the application of modern biotechnology to breeding in the form of genetically modified varieties is often based on concerns about concentration in the sector, as well as the more conventional suspicions concerning the integrity and the trustworthiness risk assessment policies and procedures. If breeding produces new varieties with primarily agronomic characteristics that are of benefit to farmers, but not directly relevant to consumers, then the latter are less likely to appreciate these.

Clearly the results obtained are based partly on the specific formulations for demand of the final production good, as well as the distribution of farms. An important extension to explore is to take a more general approach to see which propositions can be developed when only general characteristics of the functions are assumed[13]. This is complicated by the interdependence among the farms and is left to further work. It is possible to anticipate though that the result of a fixed proportion of farms purchasing the seed from the monopolist is likely to give way in such a setting to a less determinate result which might reveal more complicated tradeoffs in interests concerning appropriability. For example, it is logical to expect that higher appropriability and a level of innovation would decrease the proportion of farms finding it profitable to purchase the monopolist's seed, whose profits may be maximized by attenuating the corresponding increases in price.

A more fundamental limitation to this framework is its essentially static nature. As has been done by many authors, the decision to invest in quality is interpreted as encompassing the dynamic nature of the issue. One can then also compare appropriability that maximizes innovation versus appropriability that maximizes current welfare, presupposing that long term welfare will depend even more on innovation. The intermediate product case analyzed in the current paper illustrates though that whether consumers surplus would be monotonically increasing in innovation may not necessarily be the case, and an analysis that differentiates between different circumstances might be warranted. More generally, a dynamic model is also an obvious extension, either through multiple decision periods,

[13] As done by Bae and Choi (2006).

or beginning with a simple two-period framework. This perspective is quite relevant for the agricultural sector, given the predator-prey relationship characterizing the development of new crop varieties in the face of continually evolving pests (Goeschl and Swanson, 2003). Innovation is necessary simply to maintain current production levels and thus consumer welfare.

To examine some of the issues at stake with the coming into force of the TRIPS Agreement and the requirement that all WTO members provide for IPR protection of agricultural plant varieties, the analysis is extended to a two-country setting. In an autarkic situation, the monopolist, based in the North, begins marketing its seed to farms in the South. But now, as the level of quality is given, diffusion of the monopolist's product in the South, including through less productive copies, is maximized with a minimal level of appropriability, which also benefits consumers more by raising production. In an agricultural context, minimal appropriability also maximizes the number of farms able to produce. Given food security concerns at both household and national level, this can help explain reluctance among Southern governments to accept and implement TRIPS obligations, as well as opposition to such policies by more modernized and productive segments of the farm sector.

In the situation where there is international trade in the farm product, the interests of farms in the North and the South become interdependent, as do those of consumers in both countries. The analysis has shown how farms in the North, both those purchasing seed and those using copied seed would be supportive of a raising of the appropriability level in the South, while farms there would not benefit. Such pressure has been witnessed, but has had little or no support from consumers in either region which may reflect the fact that this would raise prices for them.

As admitted, all of this two-country analysis takes the level of quality as given. An interesting extension, in the same spirit as a more dynamic formulation, would be to examine the subsequent effect of different levels of appropriability on the monopolist's incentive to invest in innovation. This is relevant to the TRIPS perspective, but it may also be interesting to allow for the emergence and entry of a competing innovator in the South, possibly facing a choice between piracy and its own innovation. Nonetheless, the portrayal of different interests in the current paper may correspond reasonably well to the initial, and to some extent ongoing, debates concerning TRIPS and Article 27(3)b, in which stakeholders are possibly reflecting relatively short term perspectives.

A final note concerns the potential applicability of the analysis here to the context of digital products subject to copyright protection, such as software or entertainment media, which motivated the models upon which the present paper builds. The analysis of Bae and Choi (2006) and Belleflamme and Picard (2007) considers products that are typically final consumption goods, such as digital music or video. Many of the most widely used software products though, such as operating systems and office applications, are used as much if not more by businesses and may also be considered as intermediate goods. Thus, further pursuing this line of analysis may be of broader relevance.

5 Annex

5.1 Proof of Proposition 2

Total profits of farms purchasing from the monopolist are maximized with maximum appropriability.

Profits for farmers purchasing the monopolist's seed are calculated by integrating the expression for profits at θ over the interval $(\theta_1, \bar{\theta})$, recalling that $\theta_1 = \bar{\theta}/2$:

$$\begin{aligned}
\tau_1 &= \int_{\theta_1}^{\bar{\theta}} (g\theta u - p_1)\,\mathrm{d}\theta \\
&= \int_{\theta_1}^{\bar{\theta}} \left(\left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{4\bar{\theta}Sr(1-\delta)} \cdot \theta \right] - \frac{\delta c}{2(1-\delta)} - \frac{\delta^2 b^2 \bar{\theta}}{8Sr} - c \right) \mathrm{d}\theta \\
&= \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{8\bar{\theta}Sr(1-\delta)} \right] (\bar{\theta}^2 - \theta_1^2) \\
&\quad - \left[\frac{\delta c}{2(1-\delta)} + \frac{\delta^2 b^2 \bar{\theta}}{8Sr} + c \right] (\bar{\theta} - \theta_1) \\
&= \frac{3b^2\delta\bar{\theta}^2 - 2b^2\delta^2\bar{\theta}^2}{32Sr} + \frac{3\bar{\theta}c - 2\delta\bar{\theta}c}{8(1-\delta)} - \frac{\bar{\theta}c}{2} \\
&= \frac{\delta(3-2\delta)b^2\bar{\theta}^2}{32Sr} + \frac{\bar{\theta}c(3-2\delta)}{8(1-\delta)} - \frac{\bar{\theta}c}{2}\,. \qquad (15)
\end{aligned}$$

The effect of different levels of appropriability on farm profits is examined by differentiating τ_1 with respect to δ:

$$\frac{\mathrm{d}\tau_1}{\mathrm{d}\delta} = \frac{(3-4\delta)b^2\bar{\theta}^2}{32Sr} + \frac{\bar{\theta}c}{8(1-\delta)^2}$$

This expression is positive for $0 < \delta < 3/4$, meaning that farm profits are increasing in appropriability at least until that level. A local maximum or minimum would imply that

$$(1-\delta)^2(4\delta - 3) = \frac{4Scr}{\bar{\theta}b^2}$$

and interest centers on situations where this expression > 0, which implies that

$$\begin{aligned}
4\delta^3 - 11\delta^2 - 2\delta - 3 &> 0 \\
\Rightarrow 4\delta^3 - 11\delta^2 - 2\delta &> 0 \\
\Rightarrow \delta(4\delta^2 - 11\delta - 2) &> 0
\end{aligned}$$

for $3/4 < \delta < 1$. The quadratic expression $4\delta^2 - 11\delta - 2$ has the roots $\delta = (11 \pm \sqrt{153})/8 = -0.17$ and 2.92 and a minimum at $\delta = 11/8$. Therefore $\delta(4\delta^2 - 11\delta - 2) < 0$ over the interval $3/4 < \delta < 1$, and τ_1 is increasing in δ over this interval (with $\lim_{\delta \to 1} \tau_1 \to \infty$) . □

5.2 Proof of Proposition 3

Profits for farms using copied seed could be maximized at the moderate level of appropriability $\delta = 1/2$ provided the strength of demand for the farm's product sufficiently exceeds the cost of producing seed.

The expression for profits of farms producing copied seed can be derived integrating the appropriate expression for over the interval (θ_c, θ_1):

$$\begin{aligned}
\tau_c &= \int_{\theta_c}^{\theta_1} [g(1-\delta)\theta u - c]\,\mathrm{d}\theta \\
&= \int_{\theta_c}^{\theta_1} \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{4\bar{\theta}Sr}\cdot\theta - c\right]\mathrm{d}\theta \\
&= \left[\frac{b^2\delta(1-\delta)\bar{\theta} + 4Scr}{8\bar{\theta}Sr}\right]\left[\frac{\bar{\theta}^2}{4} - \frac{16\bar{\theta}^2 S^2c^2r^2}{[\bar{\theta}\delta(1-\delta)b^2 + 4Scr]^2}\right] \\
&\quad -c\left[\frac{\bar{\theta}}{2} - \frac{4\bar{\theta}Sc^2r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr}\right] \\
&= \frac{\bar{\theta}^2\delta(1-\delta)b^2 + 4\bar{\theta}Scr}{32Sr} + \frac{2\bar{\theta}Sc^2r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{\bar{\theta}c}{2} \\
&= \frac{\bar{\theta}^2\delta(1-\delta)b^2}{32Sr} + \frac{2\bar{\theta}Sc^2r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{3}{8}\bar{\theta}c
\end{aligned} \tag{16}$$

As this is quite nonlinear in δ, we maximize profit with respect to appropriability:

$$\frac{\mathrm{d}\tau_c}{\mathrm{d}\delta} = \frac{(1-2\delta)b^2\bar{\theta}^2}{32Sr} - \frac{2\bar{\theta}^2Sc^2rb^2(1-2\delta)}{[\bar{\theta}\delta(1-\delta)b^2 + 4Scr]^2};$$

and clearly $\delta = 1/2$ is one solution to $\mathrm{d}\tau_c/\mathrm{d}\delta = 0$. Other solutions are found by looking for other roots to this equation,

$$\begin{aligned}
\frac{\mathrm{d}\tau_c}{\mathrm{d}\delta} = 0 \Rightarrow &\quad \tfrac{(1-2\delta)b^2\bar{\theta}^2}{(1-2\delta)b^2\bar{\theta}^2} = \tfrac{64S^2c^2r^2}{[\bar{\theta}\delta(1-\delta)b^2+4Scr]^2} \\
\Rightarrow &\quad \bar{\theta}^2\delta^2(1-\delta)^2b^4 + 8Scr\bar{\theta}\delta(1-\delta)b^2 - 48S^2c^2r^2 = 0 \\
\Rightarrow &\quad \left[\bar{\theta}\delta(1-\delta)b^2 + 12Scr\right]\left[\bar{\theta}\delta(1-\delta)b^2 - 4Scr\right] = 0 \\
\Rightarrow &\quad \bar{\theta}\delta(1-\delta)b^2 = 4Scr
\end{aligned}$$

since the other root would imply that δ is not in $(0,1)$. Solving this using the formula for quadratic roots yields,

$$\begin{aligned}
\delta &= \frac{\bar{\theta}b^2 \pm \sqrt{\bar{\theta}^2b^4 - 16\bar{\theta}b^2Scr}}{2\bar{\theta}b^2} \\
&= \frac{1}{2} \pm \sqrt{\frac{1}{4} - \frac{4Scr}{\bar{\theta}b^2}}.
\end{aligned} \tag{17}$$

Both roots will be in $(0,1)$, provided that

$$\frac{4Scr}{\bar{\theta}b^2} < \frac{1}{4}, \tag{18}$$

since an equality leads to the known root $\delta = 1/2$. Although the model is not defined at $\delta = 0$ or $\delta = 1$, evaluating $\mathrm{d}\tau_c/\mathrm{d}\delta$ at these values indicates that the derivative is negative at values of δ just exceeding 0 and is positive at values approaching 1. Therefore given (18), there can be one local maximum at $\delta = 1/2$ for $\mathrm{d}\tau_c/\mathrm{d}\delta$ and two local minima in the interval $\delta \in (0, 1)$, with the minima defined by (17). By noting that $\tau_c = \bar{\theta}c/8$ for $\delta = 0$ or $\delta = 1$, total profits for all farms purchasing copied seed (τ_c) are essentially the same with either minimum or maximum appropriability, although with minimum appropriability these profits are divided over a much larger group (θ_c will be lower). If the local maximum for total profits exceeds the value at minimum and maximum appropriability, then

$$\frac{\bar{\theta}^2\delta(1-\delta)b^2}{32Sr} + \frac{2\bar{\theta}Sc^2r}{\bar{\theta}\delta(1-\delta)b^2 + 4Scr} - \frac{3\bar{\theta}c}{8} > \frac{\bar{\theta}c}{8}\,.$$

Evaluating at $\delta = 1/2$ implies

$$\frac{\bar{\theta}b^2}{128Sr} + \frac{8Sc^2r}{\bar{\theta}b^2 + 16Scr} > \frac{c}{2} \text{ or}$$

$$\begin{aligned}
\frac{8Sc^2r}{\bar{\theta}b^2 + 16Scr} &> \frac{64Scr - \bar{\theta}b^2}{128Sr} \\
1024S^2c^2r^2 &> \left[64Scr - \bar{\theta}b^2\right]\left[\bar{\theta}b^2 + 16Scr\right] \\
1024S^2c^2r^2 &> 1024S^2c^2r^2 + 48Scr\bar{\theta}b^2 - \bar{\theta}^2b^4 \\
\Rightarrow \bar{\theta}b^2 &> 48Scr \text{ which can be rearranged as} \\
\frac{4Scr}{\bar{\theta}b^2} &< \frac{1}{12}\,. \square
\end{aligned} \tag{19}$$

This sets a stricter limit than in (18) and can be interpreted as follows: if the strength of demand for the final product is sufficiently larger, in relative terms, than the cost of producing and copying seed, then total profits for farms using copied seed will be maximized with "moderate" appropriability, defined as $\delta = 1/2$. The range of values for δ for which total profits exceed those at minimum or maximum appropriability rises as the ratio between final demand and cost of the input increases.

5.3 Proof of Proposition 4

Consumers benefit most from a moderate level of appropriability, set at $\delta = 1/2$.

Substituting (6) into (1),

$$g = \frac{b}{S\bar{\theta}} + \frac{4cr}{\delta(1-\delta)b\bar{\theta}^2}\,.$$

Differentiating,

$$\frac{\mathrm{d}g}{\mathrm{d}\delta} = \frac{4cr(2\delta-1)}{b\bar{\theta}^2\delta^2(1-\delta)^2}$$

and setting to 0 implies that $\delta = 1/2$. The second derivative is

$$\begin{aligned}
\frac{\mathrm{d}^2 g}{\mathrm{d}\delta^2} &= \frac{4cr}{b\bar{\theta}^2}\left[\frac{2\delta^2(1-\delta)^2 - (2\delta-1)(2\delta-6\delta^2+4\delta^3)}{\delta^4(1-\delta)^4}\right] \\
&= \frac{8cr}{b\bar{\theta}^2}\left[\frac{\delta^2(1-\delta)^2 + \delta(1-2\delta)^2(1-\delta)}{\delta^4(1-\delta)^4}\right] \\
&= \frac{8cr}{b\bar{\theta}^2}\left[\frac{\delta(1-\delta) + (1-2\delta)^2}{\delta^3(1-\delta)^3}\right] .
\end{aligned}$$

Whether this is positive or negative at $\delta = 1/2$ depends on

$$\begin{aligned}
&\delta^2(1-\delta)^2 + \delta(1-2\delta)^2(1-\delta) \\
&= -3\delta^3 + 6\delta^2 - 4\delta + 1 \\
&= 0.125 > 0, \quad \text{evaluated at } \delta = 1/2 .
\end{aligned}$$

Therefore the consumer price g of the farm product is minimized at $\delta = 1/2$.. □

5.4 Proof of Proposition 6

Total profits of farms in the South purchasing the monopolist's seed are maximized with a maximum level of appropriability that is feasible.

Profits for farms purchasing the monopolist's seed are determined, as above, by

$$\begin{aligned}
\tau_{1S} &= \int_{\theta_{1S}}^{\bar{\theta}_S} (g_S u\theta - p_{1S})\mathrm{d}\theta \\
&= \int_{\theta_{1S}}^{\bar{\theta}_S} \left[\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\cdot\theta - p_{1S}\right]\mathrm{d}\theta \\
&= \left[\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\cdot\frac{\theta^2}{2} - p_{1S}\theta\right]_{\theta_{1S}}^{\bar{\theta}_S} \\
&= \left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right)\left(\frac{\bar{\theta}_S^2}{2} - \frac{\bar{\theta}_S^2}{8}\right) - p_{1S}\frac{\bar{\theta}_S}{2} \\
&= \frac{3\bar{\theta}_S}{8}\left(\frac{b_S u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S}{2}\left(\frac{\delta_S[b_S(1-\delta_S)u + S_S c]}{2S_S(1-\delta_S)} + c\right) \\
&= \frac{3\bar{\theta}_S}{8}\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\delta_S\bar{\theta}_S}{4}\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S c}{2} \\
&= \frac{\bar{\theta}_S}{8}(3-2\delta_S)\left(\frac{b_S(1-\delta_S)u + S_S c}{S_S(1-\delta_S)}\right) - \frac{\bar{\theta}_S c}{2} \\
&= \frac{\bar{\theta}_S}{8}(3-2\delta_S)\left(\frac{b_S u}{S_S} + \frac{c}{1-\delta_S}\right) - \frac{\bar{\theta}_S c}{2} .
\end{aligned}$$

Maximizing with respect to δ_S,

$$\begin{aligned}
\frac{\partial \tau_{1S}}{\partial \delta_S} &= \frac{\bar{\theta}_S}{8}\left(\frac{3c}{(1-\delta_S)^2} - \frac{2b_S u}{S_S} - \frac{2c(1-\delta_S)+2\delta_S c}{(1-\delta_S)^2}\right) \\
&= \frac{\partial \tau_{1S}}{\partial \delta_S}\frac{\bar{\theta}_S}{8}\left(\frac{c}{(1-\delta_S)^2} - \frac{2b_S u}{S_S}\right), \text{ and } = 0 \Rightarrow \\
(1-\delta_S)^2 &= \frac{S_S c}{2b_S u} \text{ or } \delta_S = 1 \pm \sqrt{\frac{S_S c}{2b_S u}}\,. \qquad (20)
\end{aligned}$$

Since $\partial^2\tau_{1S}/\partial\delta^2 = \bar{\theta}_S c/4(1-\delta_S)^3 > 0$, then the solution is a minimum. A minimum point will be found in $(0,1)$ if $S_S c < b_S u$ (and the negative root is taken). It is also clear that τ_{1S} approaches $\frac{\bar{\theta}_S}{8}\left(\frac{3b_S u}{S_S} + 3c\right) - \frac{\bar{\theta}_S c}{2}$ as δ_S approaches 0, but tends to ∞ as δ_S approaches 1. Therefore, while a minimum might be found in the range $(0,1)$, the maximum will always be as $\delta_S \to 1$. □

5.5 Proof of Proposition 7

Under autarky, total profits for farms in the South using copied seed will be maximized with a minimal level of appropriability if the strength of demand sufficiently exceeds the cost of producing seed.

Profits for farms using copied seed are

$$\begin{aligned}
\tau_{cS} &= \int_{\theta_{cS}}^{\theta_{1S}} [g_S(1-\delta_S)u\theta - c]\,\mathrm{d}\theta \\
&= \left[\frac{b_S(1-\delta_S)u}{S_S\bar{\theta}_S} + \frac{c}{\bar{\theta}}\right]\left[\frac{\theta_{1S}^2}{2} - \frac{\theta_{cS}^2}{2}\right] - c(\theta_{1S} - \theta_{cS}) \\
&= \frac{b_S(1-\delta_S)u + S_S c}{S_S\bar{\theta}_S}\left[\frac{\bar{\theta}_S^2}{8} - \frac{S_S^2\bar{\theta}^2 c^2}{2[b_S(1-\delta_S)u + S_S c]^2}\right] - c\left[\frac{\bar{\theta}_S}{2} - \frac{S_S\bar{\theta}_S c}{[b_S(1-\delta_S)u + S_S c]}\right] \\
&= \frac{\bar{\theta}_S[b_S(1-\delta_S)u + S_S c]}{8S_S} + \frac{S_S\bar{\theta}_S c^2}{2[b_S(1-\delta_S)u + S_S c]} - \frac{\bar{\theta}_S c}{2}\,. \qquad (21)
\end{aligned}$$

The first term is increasing in δ_S and the second term, decreasing, which implies counteracting effects of appropriability on total farm profits. Maximizing profits with respect to δ_S leads to the following:

$$\frac{\partial \tau_{cS}}{\partial \delta_S} = -\frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S\bar{\theta}_S c^2 b_S u}{2[b_S(1-\delta_S)u + S_S c]^2} \text{ and } \frac{\partial \tau_{cS}}{\partial \delta_S} = 0 \;\Rightarrow$$

$$\begin{aligned}
[b_S(1-\delta_S)u + S_S c]^2 &= 4S_S^2 c^2 \\
b(1-\delta_S) &= S_S c \\
\delta_S &= 1 - \frac{S_S c}{b_S u} \qquad (22)
\end{aligned}$$

which will be in the interval $(0,1)$ if $S_S c < b_S u$. Since

$$\frac{\partial^2 \tau_{cS}}{\partial \delta_S^2} = \frac{S_S\bar{\theta}_S c^2 b_S^2 u^2}{[b_S(1-\delta_S)u + S_S c]^3} > 0\,,$$

the critical point for δ_S is minimum, implying that total profits will be maximized at either the minimum or maximum level of appropriability. As $\delta_S \to 1$,

$$\frac{\partial \tau_{cS}}{\partial \delta_S} \to -\frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta} c^2 b_S u}{2S_S^2 c^2} = \frac{3\bar{\theta}_S b_S u}{8S_S} > 0$$

and so the maximum value for τ_{cS} could be at this end of the interval $(0,1)$; it would be at the other lower end of the interval if $S_S c < b_S u$ by a sufficient amount. To determine this, note that total profits for farms using copied seed, from 21, can be written

$$\tau_{cS} = \frac{\bar{\theta}_S b_S(1-\delta_S)u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2[b_S(1-\delta_S)+S_S c]} - \frac{3\bar{\theta}_S c}{8}.$$

As $\delta_S \to 0$,

$$\tau_{cS} \to \frac{S_S \bar{\theta}_S c^2}{2S_S c} - \frac{3\bar{\theta}_S c}{8} = \frac{\bar{\theta}_S c}{8}$$

and as $\delta_S \to 1$,

$$\tau_{cS} \to \frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2(b_S u + S_S c)} - \frac{3\bar{\theta}_S c}{8}.$$

So for the value of τ_{cS} to be greater as $\delta_S \to 0$, than as $\delta_S \to 1$, then

$$\begin{aligned}
\frac{\bar{\theta}_S b_S u}{8S_S} + \frac{S_S \bar{\theta}_S c^2}{2(b_S u + S_S c)} - \frac{\bar{\theta}_S c}{2} &> 0 \\
\frac{b_S u(b_S u + S_S c) + 4S_S^2 c^2 - 4S_S c(b_S u + S_S c)}{8S_S(b_S u + S_S c)} &> 0 \\
b_S u(b_S u - 3S_S c) &> 0 \\
\Rightarrow S_S c &< \frac{b_S u}{3}. \qquad (23)
\end{aligned}$$

Thus, if $S_S c < b_S u$, then the value of δ_S which minimizes total farm profits (using copied seed) is between 0 and 1. If $b_S u/3 < \delta_S < b_S u$, then profits will be maximized at the maximal level of appropriability (as $\delta_S \to 1$). If $S_S c < b_S u/3$, then profits will be maximized at the lowest level of appropriability (as $\delta_S \to 0$). □

5.6 Proof of Proposition 10

Given weaker final product demand and/or a larger mass of farms in the South, opening to trade in the final product market will lead to lower overall profits for farms in the North producing with copied seed, and higher overall profits for such farms in the South, provided that the strength of demand in each market is sufficiently strong relative to the cost of producing seed.

As in 5.2, profits for farms using copied seed in country i (see (16)) can be written as

$$\begin{aligned}
\tau_{ci} &= \int_{\theta_{ci}}^{\theta_{1i}} [g_i(1-\delta_i)u\theta - c]\,\mathrm{d}\theta \\
&= \frac{g_i(1-\delta_i)u}{2}\left(\theta_{1i}^2 - \theta_{ci}^2\right) - c\left(\theta_{1i} - \theta_{ci}\right) \\
&= \frac{g_i(1-\delta_i)u}{2}\left(\frac{\bar{\theta}_i^2}{4} - \frac{c^2}{g_i^2(1-\delta_i)^2u^2}\right) - c\left(\frac{\bar{\theta}_i}{2} - \frac{c}{g_i(1-\delta_i)u}\right) \\
&= \frac{g_i(1-\delta_i)u\bar{\theta}_i^2}{8} + \frac{c^2}{2g_i(1-\delta_i)u} - \frac{c\bar{\theta}_i}{2}\ . \qquad (24)
\end{aligned}$$

The relationship to g_i is unclear in this expression, but differentiating profits leads to

$$\frac{\partial \tau_{ci}}{\partial g_i} = \frac{(1-\delta_i)u\bar{\theta}_i^2}{8} - \frac{c^2}{2g_i^2(1-\delta_i)u}\ ; \qquad (25)$$

For this derivative to be positive,

$$\begin{aligned}
2g_i^2(1-\delta_i)^2u^2\bar{\theta}_i^2 &> 8c^2 \text{ or} \\
g_i^2(1-\delta_i)^2u^2\bar{\theta}_i^2 &> 4c^2\ . \qquad (26)
\end{aligned}$$

Substituting for

$$g_iu = \frac{b_iu}{S_i\bar{\theta}_i} + \frac{c}{\bar{\theta}_i(1-\delta_i)}$$

leads to

$$\begin{aligned}
(1-\delta_i)^2\bar{\theta}_i^2\left(\frac{b_iu}{S_i\bar{\theta}_i} + \frac{c}{\bar{\theta}_i(1-\delta_i)}\right)^2 &> 4c^2 \\
\Rightarrow \frac{b_i(1-\delta_i)}{S_i} &> 2c \\
\frac{b_i(1-\delta_i)}{S_i} &> c \qquad (27)
\end{aligned}$$

Therefore, if the strength of demand sufficiently exceeds the cost of producing seed, then the profits of farms using copied seed increase in final product demand. So if trade leads to a world price, g_W, lower than the price in the North under autarky, g_N, then farms using copied seed in the North lose from trade, and conversely for farms in the South using copied seed.

References

Aghion, P., Harris, C., Howitt, P. and Vickers, J. (2001). Competition, imitation and growth with step-by-step innovation. *Review of Economic Studies* 68: 467–492.

Aghion, P. and Howitt, P. (1998). *Endogenous growth theory*. Cambridge, M.A: MIT Press.

Alston, J. M. and Venner, R. J. (2002). The effects of the US plant variety protection act on wheat genetic improvement. *Research Policy* 31: 527–542.

Ambec, S., Langinier, C. and Lemarie, S. (2008). Incentives to reduce crop trait durability. *American Journal of Agricultural Economics* 90: 379–391.

Aoki, R. and Prusa, T. J. (1997). Sequential versus simultaneous choice with endogenous quality. *International Journal of Industrial Organization* 15: 103–121.

Arrow, K. J. (1959). Economic welfare and the allocation of resources for invention. Tech. rep., RAND Corporation, Santa Monica, CA.

Bae, S. H. and Choi, J. P. (2006). A model of piracy. *Information Economics and Policy* 18: 303–320.

Belleflamme, P. and Picard, P. M. (2007). Piracy and competition. *Journal of Economics & Management Strategy* 16: 351–383.

Boccard, N. and Wauthy, X. (2005). Enforcing domestic quality dominance through quotas. *Review of International Economics* 13: 250–261.

Boccard, N. and Wauthy, X. (2006). Quality choice, sales restriction and the mode of competition. *The Manchester School* 74: 64–84.

Boom, A. (1995). Asymmetric international minimum quality standards and vertical differentiation. *Journal of Industrial Economics* 43: 101–119.

Burton, D. M., Love, H. A., Ozertan, G. and Taylor, C. R. (2005). Property rights protection of biotechnology innovations. *Journal of Economics & Management Strategy* 14: 779–812.

Cabrales, A. and Motta, M. (2001). Country asymmetries, endogenous product choice and the timing of trade liberalization. *European Economic Review* 45: 87–107.

Choi, P., Bae, S. H. and Jun, J. (2010). Digital piracy and firms' strategic interactions: The effects of public copy protection and DRM similarity. *Information Economics and Policy* 22: 354–364.

Dijk, T. van (1995). Innovation incentives through third-degree price discrimination in a model of patent breadth. *Economics Letters* 47: 431–35.

Fulton, M. and Giannakas, K. (2004). Inserting GM products into the food chain: The market and welfare effects of different labeling and regulatory regimes. *American Journal of Agricultural Economics* 86: 42–60.

Ghijsen, H. (1998). Plant variety protection in a developing and demanding world. *Biotechnology and Development Monitor* 36: 2–5.

Giannakas, K. and Yiannaka, A. (2008). Market and welfare effects of second-generation, consumer-oriented GM products. *American Journal of Agricultural Economics* 90: 152–171.

Goeschl, T. and Swanson, T. (2003). Pests, plagues, and patents. *Journal of the European Economic Association* 1: 561–575.

Heisey, P. W. and Brennan, J. P. (1991). An analytical model of farmers' demand for replacement seed. *American Journal of Agricultural Economics* 73: 1044–1052.

Helpman, E. (1993). Innovation, imitation, and intellectual property rights. *Econometrica* 61: 1247–1280.

Koning, N. and Mol, A. P. J. (2009). Wanted: institutions for balancing global food and energy markets. *Food Security* 1: 291–303.

Lai, E. L. C. and Qiu, L. D. (2003). The north's intellectual property rights standard for the south. *Journal of International Economics* 59: 183–209.

Lambertini, L. and Orsini, R. (2005). The existence of equilibrium in a differentiated duopoly with network externalities. *Japanese Economic Review* 56: 55–66.

Leskien, D. and Flitner, M. (1997). Intellectual property rights and plant genetic resources: optons for a sui generis system. Issues in Genetic Resources No. 7, International Plant Genetic Resources Institute (IPGRI), Rome.

Lesser, W. (1997). Assessing the implications of intellectual property rights on plant and animal agriculture. *American Journal of Agricultural Economics* 79: 1584–1591.

Moschini, G. and Lapan, H. (1997). Intellectual property rights and the welfare impacts of agricultural R & D. *American Journal of Agricultural Economics* 79: 1229–1242.

Motta, M. (1993). Endogenous quality choice: price vs quantity competition. *Journal of Industrial Economics* 41: 113–131.

Motta, M., Thisse, J. and Cabrales, A. (1997). On the persistence of leadership or leapfrogging in international trade. *International Economic Review* 38: 809–824.

Mussa, M. and Rosen, S. (1978). Monopoly and product quality. *Journal of Economic Theory* 18: 301–317.

O'Donoghue, T., Scotchmer, S. and Thisse, J. F. (1998). Patent breadth, patent life, and the pace of technological progress. *Journal of Economics and Management Strategy* 7: 1–32.

O'Donoghue, T. and Zweimuller, J. (2004). Patents in a model of endogenous growth. *Journal of Economic Growth* 9: 81–123.

Oladi, R., Beladi, H. and Chau, N. (2008). Multinational corporations and export quality. *Journal of Economic Behavior and Organization* 65: 147–155.

Plastina, A. and Giannakas, K. (2007). Market and welfare effects of GMO introduction in small open economies. *AgBioForum* 10: Article 5.

Scotchmer, S. (2004). *Innovation and incentives*. Cambridge MA: MIT Press.

Shaked, A. and Sutton, J. (1982). Relaxing price competition through product differentiation. *Review of Economic Studies* 49: 3–13.

Tongeren, F. van and Eaton, D. (2004). The case for differentiated appropriability in intellectual property rights for plant varieties. In Evenson, R. and Santaniello, V. (eds), *The regulation of agricultural biotechnology*. Wallingford, UK: CABI Publishing, 109–118.

Toshimitsu, T. (2003). Optimal R&D policy and endogenous quality choice. *International Journal of Industrial Organization* 21: 1159–1178.

Valletti, T. M. (2006). Differential pricing, parallel trade, and the incentive to invest. *Journal of International Economics* 70: 314–324.

Yerokhin, O. and Moschini, G. (2008). Intellectual property rights and crop-improving R&D under adaptive destruction. *Environmental and Resource Economics* 40: 53–72.

Zhou, D., Spencer, B. J. and Vertinsky, I. (2002). Strategic trade policy with endogenous choice of quality and asymmetric costs. *Journal of International Economics* 56: 205–232.