THE ECONOMICS OF INTELLECTUAL PROPERTY RIGHTS UNDER IMPERFECT ENFORCEMENT

Konstantinos Giannakas*
Assistant Professor
Department of Agricultural Economics
University of Nebraska-Lincoln
216 H.C. Filley Hall
Lincoln NE 68583-0922

Phone: (402) 472-2041
Fax: (402) 472-3460
kgiannakas@unl.edu

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Abstract - The introduction of intellectual property rights (IPRs) is one of the most notable features of agricultural biotechnology. So are growing concerns about the widespread violation of IPRs in developing countries. This paper develops a model of heterogeneous producers to examine the economic causes of IPR infringement and its consequences for the welfare of the interest groups and the pricing and adoption of a new technology (i.e., a genetically modified seed) in the context of a small open developing economy. Enforcement of IPRs, and pricing and adoption of the new technology are modeled as a sequential game between the government that enforces the IPRs, a foreign innovating firm that prices the new technology, and the developing country's producers who make the production and cheating decisions. Analytical results show that producer compliance with the provisions of IPRs is not the natural outcome of self-interest and complete deterrence of IPR infringement is not always economically optimal. IPR infringement affects the welfare of the interest groups and has important ramifications for the pricing and adoption of the new technology. The quantitative nature of the results depends critically on the existing labeling regime. The analysis also shows that differences in the level of IPR enforcement provide an alternative justification for (and explanation of) differences in the pricing of the new technology in different countries around the world – a strategy adopted by leading innovators in the sector. Finally, the results suggest that if the penalties for IPR infringement under the TRIPs agreement follow the custom of retaliatory sanctions under the GATT, enforcement of IPRs will remain imperfect and the innovators' ability to obtain value for their biotech traits will still be limited.

Keywords: Biotechnology, Intellectual Property Rights, Enforcement, Infringement, TRIPs Agreement

Parallel revolutions in molecular biology and the legal framework that assigns intellectual property rights (IPRs) to plant genetic resources have resulted in the emergence of agricultural biotechnology and the introduction of genetically modified (GM) products into the food system. IPRs create economic incentives for research and development by making the innovator the residual claimant of the benefits associated with the new technology (Perrin, 1994). Whereas IPRs purport to protect intellectual property, full appropriation of the benefits associated with the innovation is not a given.

When infringement of IPRs (i.e., piracy) is profitable, rational economic agents' compliance with IPR provisions is by no means assured. Costly monitoring and enforcement are required to deter unauthorized (illegal) use of the new technology. Experience from various countries around the world indicates that IPR enforcement is far from being perfect and most (if not all) successful innovations are subject to piracy. This is particularly true in developing countries where there is a growing opposition to the very granting of IPRs for agricultural crops. In addition to the domestic surplus transfers to foreign firms/IPR holders in the form of monopolistic rents, concerns of developing countries include environmental safety and food security (Mansfield, 1983; Taylor, 1983; Ringo, 1994). The result is a widespread violation of innovators' IPRs in these countries that has become a major international issue.

The concerns about IPR infringement resulted in the Agreement on Trade Related Aspects of Intellectual Property (TRIPs) during the Uruguay Round of GATT negotiations. The TRIPs agreement is administered by the World Trade Organization (WTO) and allows countries whose innovating firms' IPRs are being violated to retaliate and penalize the violating country/enforcer of IPRs under the GATT. Even though the TRIPs agreement is to come fully into force within the next few years, an agreement on the magnitude of the fines that can be imposed is yet to be reached.

While innovators have been active in lobbying for the effective enforcement of their IPRs, their pricing behavior reveals a preferential treatment of customers that respect their IPRs the least. It is usually the case that the prices charged by multinational firms/IPR holders in markets with lax enforcement of IPRs are significantly lower than the prices charged in markets where IPRs are effectively enforced. In Argentina for instance where 50 to 85% of the Roundup Ready soybean seeds grown are either seeds purchased from the black market (25 to 50%) or/and seeds saved by the farmer from the previous year's crop (25 to 35%), the prices charged by the innovating firm (Monsanto) are less than half the prices charged to US soybean producers (US General Accounting Office, 2000). This discrepancy has raised concerns by US producers who feel that they are being penalized for being "honest" (Holmberg, 2000). One conclusion of this paper is that they are probably right.

Although there is a growing literature on the consequences of IPR introduction for investment in research, the development of improved varieties, the structure of the biotechnology sector, the international trade of products of biotechnology, and the welfare of interest groups (Just and Hueth, 1993; Perrin, 1994; Moschini and Lapan, 1997; Lesser, 1998; Hayenga, 1998; Perrin, 1999; Alston and Venner, 2000; Fulton and Giannakas, 2000), the analysis of IPR infringement by the users of biotechnology is rather heuristic in nature. Studies on IPR enforcement problems have mainly focused on new technology imitation by rival firms (for a review of this literature see Perrin (1999)). Despite the incentives for, and the prevalence of, IPR infringement by producers, this issue has not been analyzed systematically.

The objective of this paper is to examine the economic causes of IPR infringement by producers and its consequences for the welfare of the interest groups and the pricing and adoption of the new technology. Specifically, this study analyzes the causes and consequences of unauthorized use by producers of genetically modified seed that is developed and produced by a foreign seed company and is protected by IPRs (e.g., case of Monsanto in Argentina and most markets around the world). The case where producers comply completely with the provisions of IPRs (or, alternatively, the case where IPR enforcement is perfect) is also examined and used as a benchmark for the analysis of the consequences of IPR infringement.

Although the enforcement of innovator's rights is an issue of relevance for most (if not all) areas where IPRs are introduced, the focus of this study is on enforcement of IPRs in a developing country. The developing country is a small open economy in the production of both the traditional and GM crops (i.e., the prices of these crops are not affected by domestic production decisions), and enforcement of the seed company's IPRs is the responsibility of the domestic government.

IPR enforcement, pricing and adoption of the new technology (GM seed) are modeled as a sequential game between a government that is responsible for the enforcement of IPRs, the innovator who prices the GM seed, and the producers who make the production and cheating decisions. The government moves first and determines its IPR enforcement policy knowing exactly how its decisions will affect the (optimizing) behavior of the seed company and producers. Once the audit policy and the penalties for IPR infringement are announced, the innovator decides on the price of the GM seed that it will supply in the domestic market. Finally, after the decisions of the government and the innovator have been carried out, the farmers decide on whether they will adopt the new technology and, if so, whether they will comply with the provisions of IPRs (i.e., pay the fee associated with the use of the GM seed).

To avoid Nash equilibria involving non-credible strategies, the problem is solved using backward induction (Kreps, 1990; Gibbons, 1992). The problem of the farmers is considered first, the problem of the innovator follows, and the solution of the government's problem determines the (subgame perfect) equilibrium enforcement of IPRs, and the price, quantity, and adoption of the new technology. Different scenarios concerning the enforcement parameters controlled by the government and the labeling regime that is in place with regards to the final GM product are examined within this framework. Finally, the analysis considers the situation in which IPR enforcement is the innovator's responsibility.

Note that this is an *ex post* analysis of IPR infringement in the sense that domestic production decisions have no effect on the development of this technology - the innovating seed company has developed the GM seed, has been granted IPRs, and its problem is to determine the price of the new technology and the quantity that will supply in the market under concern. Also, implicit in this analysis is the assumption that GM seeds used illegally (i.e., seeds bought from the black market and seeds saved by the farmer) are perfect substitutes for GM seeds purchased from the innovator - the agronomic characteristics and production potential of GM seeds purchased from the innovating firm are identical to those used illegally.

Other than formally analyzing IPR infringement, a distinct feature of this study is that it relaxes the (conventional) assumption of producer homogeneity. Instead, producers are postulated to differ in terms of age, education, experience, management skills, technology adopted, size and location of the farm, degree of specialization etc. The heterogeneity of producers in terms of production factors is a key component in the model and is critical in understanding the existence of both traditional and new technologies in the market, as well as the non-compliance with the provisions of IPRs of part (and not all) of the new technology users.

The simple model developed in this paper is consistent with much of the literature on IPRs. In addition, the model provides insights about issues (such as the pricing behavior of innovating firms, the enforcement of IPRs when audits or/and penalties are endogenous to the innovator, the effect of the existing labeling regime, and the likely effectiveness of the TRIPs agreement) that have not been examined previously.

The rest of the paper is organized as follows. Section 2 analyzes technology pricing and adoption decisions when enforcement of IPRs is perfect. Section 3 examines the causes of IPR infringement and its consequences for the welfare of the interests groups and the pricing and adoption of the new technology. Section 4 extends the analysis to the case where the final product is not labeled, and the case where enforcement is carried out by the innovating firm. Section 5 discusses the implications of the analysis for innovator's pricing strategies while Section 6 summarizes and concludes the paper.

2. Benchmark Case: Perfect Enforcement of IPRs

2.1. Producers' Problem

Consider a producer that is determining whether to produce a unit of a traditional (non-GM) crop or a unit of a new GM crop. As mentioned previously, producers are assumed to be differentiated in some fashion. Specifically, farmers are assumed to differ in the relative returns they receive from different crops, which in turn stems from differences in such things as geography, education, management skills, and technology adopted.[1] Let *A* denote the attribute that differentiates producers. A producer with attribute *A* has the following net returns function:

Net Returns Function

$$\Pi_t = p_t - p_t^s + \gamma A \qquad \text{If a unit of traditional crop is produced}$$

$$\Pi_{gm} = p_{gm} - p_{gm}^s + \phi A \qquad \text{If a unit of GM crop is produced}$$

The parameters p_t and p_{gm} are the farm prices (net of all production costs except for seed) for the traditional crop and the GM crop, respectively; p_t^s and p_{gm}^s are the costs of the seed required to produce the traditional and the GM crops, respectively; *A* is the differentiating attribute that is assumed to be uniformly distributed between 0 and 1; and γ and φ are non-negative return premium factors associated with the production of the traditional and the GM crop, respectively, so that $\gamma > \varphi$. The traditional crop receives a price premium but is more expensive to produce than its GM counterpart (i.e., $p_t > p_{gm}$

[1] A similar formulation of the producer choice problem is used by Fulton and Kelowski (1999) in examining producer benefits from the introduction of herbicide-resistant canola.

and $p_t^s > p_{gm}^s$),[2] while, to allow for a positive supply of the traditional crop, it is assumed that $\gamma - \phi > \left(p_{gm} - p_{gm}^s\right) - \left(p_t - p_t^s\right)$.

The production choice of the individual producer is determined by the relationship between the returns from the traditional crop *vis a vis* the returns from the GM crop. Figure 1 illustrates the decisions and welfare of producers. The curve Π_t depicts the net returns associated with the production of the traditional crop while the curve Π_{gm} graphs the net returns to the production of the GM crop for different levels of the differentiating attribute A. The intersection of the two net return curves determines the level of the differentiating attribute that corresponds to the indifferent producer. The producer with characteristic A_{gm} given by:

$$A_{gm} : \Pi_{gm} = \Pi_t \Rightarrow A_{gm} = \frac{\left(p_{gm} - p_{gm}^s\right) - \left(p_t - p_t^s\right)}{\gamma - \phi}$$

is indifferent between producing a unit of the traditional crop and a unit of the GM crop – the net returns associated with the production of these crops is the same. Producers "located" to the left of A_{gm} (i.e., producers with $A \in [0, A_{gm})$) find it more profitable to grow the GM crop, while producers "located" to the right of A_{gm} (i.e., producers with $A \in (A_{gm}, 1]$) find it more profitable to produce the traditional crop. Obviously, the greater is A_{gm}, the greater is the adoption of the new technology. Producer welfare is given by the area underneath the effective net returns curve shown as the dashed kinked curve in Figure 1.

Since producers have been assumed to be uniformly distributed between 0 and 1, normalizing the mass of producers at unity, A_{gm} also gives the supply of the GM product, x_{gm}, i.e.,

(1) $$x_{gm} = \frac{\left(p_{gm} - p_{gm}^s\right) - \left(p_t - p_t^s\right)}{\gamma - \phi}$$

Comparative statics results can easily be drawn from this model. More specifically, an increase in the price of the GM product shifts the Π_{gm} curve upwards and increases x_{gm} while an increase in the price of the traditional product causes an upward shift of the Π_t curve that reduces x_{gm} (i.e., $\frac{\partial x_{gm}}{\partial p_{gm}} > 0$ and

[2] When the traditional and GM crops are labeled and marketed separately, the farm price differential between the two crops is determined by the consumer demand schedules and the size of segregation costs. *Ceteris paribus*, the higher is the consumer willingness-to-pay for the traditional product versus its GM counterpart, the greater is the price premium received by producers of the traditional crop. On the other hand, the greater are the segregation costs associated with the production of the traditional crop, the lower is the effective farm price of this crop (Giannakas and Fulton, 2001).

$\frac{\partial x_{gm}}{\partial p_t} < 0$). Similarly, an increase in p_t^s causes a downward shift of the Π_t curve that increases x_{gm} while an increase in p_{gm}^s shifts the Π_{gm} curve downwards and reduces the adoption of the new technology (i.e., $\frac{\partial x_{gm}}{\partial p_t^s} > 0$ and $\frac{\partial x_{gm}}{\partial p_{gm}^s} < 0$). Obviously, if $p_{gm}^s \geq p_t^s - \left(p_t - p_{gm}\right)$ all producers will find it optimal to produce the traditional crop and $x_{gm} = 0$.

2.2. Innovator's Problem

Consider now the profit-maximizing decisions of the innovating seed company that has developed and supplies the GM seed. The seed company's problem can be seen as the determination of the price of the GM seed, p_{gm}^s , that maximizes its profits given the producers' demand schedule for GM seed, x_{gm}^s . Assuming fixed proportions between seed and farm output, the demand for GM seed faced by the seed company is given by equation (1), i.e., $x_{gm}^s = x_{gm}$, and the innovator's problem can be written as:

$$\text{(2)} \qquad \begin{aligned} & max_{p_{gm}^s} \ \pi = \left(p_{gm}^s - m\right)x_{gm}^s \\ & s.t. \ \ x_{gm}^s = x_{gm} \end{aligned}$$

where *m* represents the marginal cost of producing the GM seed. Without loss of generality, it is assumed that sales of the GM seed to the developing economy in question involve operation of the innovating firm at the part of its average cost curve where marginal costs of producing the GM seed are constant.[3]

Solving the innovator's problem shows the standard result that profits are maximized at the price-quantity combination determined by the equality of the marginal revenue and the marginal cost of production. Specifically, the profit-maximizing price of the GM seed equals:

$$\text{(3)} \qquad p_{gm}^s = \frac{\left[p_t^s - \left(p_t - p_{gm}\right)\right] + m}{2}$$

and the equilibrium supply of (and producer demand for) GM seed is given by:

$$\text{(4)} \qquad x_{gm}^s = \frac{\left[p_t^s - \left(p_t - p_{gm}\right)\right] - m}{2\left(\gamma - \phi\right)} \quad \left(= x_{gm}\right)$$

[3] Note that the marginal cost curve for the production of GM seed is likely to be either constant or decreasing. A non-increasing marginal cost is the outcome of the intellectual property used by the innovating firms (Fulton, 1997).

Figure 2 depicts the inverse demand D^s_{gm} faced by the seed company (i.e., $p^s_{gm} = \left[p^s_t - \left(p_t - p_{gm}\right)\right] - (\gamma - \phi)x^s_{gm}$) and the determination of the equilibrium price and quantity of GM seed. The profit-maximizing price-quantity combination is determined by the intersection of the marginal revenue, MR^s_{gm} , and the marginal cost, *m*, curves.[4] The shadowed area in Figure 2 shows the monopolistic rents accruing to the innovator/IPR holder while, substituting the equilibrium price (equation (3)) for p^s_{gm} in Figure 1, determines the equilibrium A_{gm} ($= x_{gm} = x^s_{gm}$) and the welfare of producers under perfect enforcement of the innovator's IPRs.[5]

3. Imperfect Enforcement of IPRs

3.1. Producers' Problem

Implicit in the previous analysis and results is the assumption that farmers comply completely with the provisions of the innovator's IPRs, i.e., those producing the GM crop pay the price associated with the use of the GM seed, p^s_{gm} . Given the possibility of purchasing seeds from the black market at a lower price, p^{s-g}_{gm} , or/and using GM seeds harvested from the previous year's crop, producers may find it economically optimal to utilize the new technology without paying the fee associated with its use. The possibility of IPR infringement arises from an informational constraint, namely producers' actions cannot be directly observed; they can only be verified through costly auditing.

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[4] The model can be easily modified to examine the profit-maximizing decisions of a small number of companies that produce very similar GM seed products. Assuming that the seed companies have the same marginal cost of production, the pricing of the GM seed is dependent on the derived demand for GM seed and the degree of market power possessed by the seed companies, i.e., $p^s_{gm} = \frac{\theta}{1+\theta}\left[p^s_t - \left(p_t - p_{gm}\right)\right] + \frac{1}{1+\theta}m$. The parameter θ is the conjectural variations elasticity that allows an examination of various types of strategic interaction among the seed companies. If, for instance, the *N* firms compete in quantities (i.e., Cournot-Nash competition), $\theta = 1/N$ and $p^s_{gm} = \frac{(1/N)\left[p^s_t - \left(p_t - p_{gm}\right)\right] + m}{1 + (1/N)}$. If the firms are engaged in an intense price competition and have no capacity constraints, $\theta = 0$ and the price of GM seed equals its marginal cost, $p^s_{gm} = m$. Finally, if the firms collude and act as a monopoly, $\theta = 1$ and $p^s_{gm} = \frac{\left[p^s_t - \left(p_t - p_{gm}\right)\right] + m}{2}$. Obviously, the less monopolistic is the seed sector (i.e., the smaller is θ), the closer to the efficient outcome is the equilibrium price-quantity combination and the greater is producer welfare.

[5] Obviously, if the intercept of D^s_{gm} lies underneath *m* (i.e., if the marginal cost of GM seed production is high), there is no quantity of the GM seed that generates positive profits and the innovator will find it optimal to not supply this market, i.e., $x^s_{gm} = 0$. In this case, the net returns curve Π^h_{gm} becomes irrelevant (i.e., farmers have no choice of producing the GM crop), and producer welfare is given by the area underneath the curve Π_t in Figure 1.

Assuming producers know with certainty the price of the GM seed, the penalty in case they are caught infringing upon seed company's IPRs, and the probability of being detected cheating, their decision on whether to cheat can be seen as decision making under uncertainty. Specifically, the individual producer's choice can be viewed as a choice between the profits associated with the production of the traditional or the GM crop with the purchased seed and the expected returns from the production of GM crop with illegally used GM seeds. Assuming neutrality towards risk and normalizing p^{s-g}_{gm} to zero, the net returns function of the producer with attribute *A* can be written as:

	$\Pi_t = p_t - p^s_t + \gamma A$	If a unit of traditional crop is produced
Net Returns Function	$\Pi^h_{gm} = p_{gm} - p^s_{gm} + \phi A$	If a unit of GM crop is produced with purchased seed
	$\Pi^c_{gm} = p_{gm} + \phi A - \delta(A)\rho$	If a unit of GM crop is produced with illegally used seed

where δ is the probability that the producer will be detected when produces the GM crop with illegally used seed and ρ is the penalty in case of detected cheating.

The detection probability takes values between zero and one (i.e., $\delta \in [0, 1]$) and is assumed to be a function of the probability that the producer will be audited (investigated) by IPR enforcers, δ_0, and farm- specific characteristics that affect the observability of producer's actions (such as location and fragmentation of the farm, managerial skills and ability of the producer) and are captured by the differentiating attribute *A*, i.e., $\delta = \delta_0 A$.[6] The greater is *A*, the closer is the correspondence between investigation and detection. For producer(s) with differentiating attribute *A*=1, auditing by IPR enforcers means (automatically) detection of potential illegal use of the GM seed. The audit probability δ_0 is assumed to be a function of the resources spent by IPR enforcers in investigating producers, Φ, where δ_0 increases with an increase in Φ, although at a decreasing rate (i.e., $\delta_0'(\Phi) \geq 0$, $\delta_0''(\Phi) \leq 0$).

Proposition 1: Producers will produce the GM crop with illegally used seed when the price of the GM seed is greater than the expected penalty from cheating.

Proof: Based on the net returns function above, the producer with characteristic *A* will use GM seed illegally when $\Pi^c_{gm} > \Pi^h_{gm} \Rightarrow p_{gm} + \phi A - \delta(A)\rho > p_{gm} - p^s_{gm} + \phi A \Rightarrow p^s_{gm} > \delta(A)\rho$.

[6] Note that this formulation of δ can also capture cases where the technology is such that investigation of producers results in the detection of IPR infringement *but* producers of different size, location etc. face different audit probabilities. In this case, δ reflects the likelihood that the producer with differentiating attribute *A* will be audited, detected, and penalized in case of using the GM seed illegally.

The price of the new technology and the level of enforcement affect the returns to IPR infringement and also the production shares of the crops under consideration. Figure 3 graphs the net returns from the traditional crop, Π_t, the GM crop produced with purchased seeds, Π_{gm}^{h}, and the GM crop produced with illegally used seed, Π_{gm}^{c}, for different levels of the differentiating attribute *A* when $p_{gm}^{s} < \frac{\delta_0 \rho \left[p_t^s - \left(p_t - p_{gm}\right)\right]}{\left(\gamma - \phi + \delta_0 \rho\right)}$. In this case, the Π_{gm}^{h} curve lies above the Π_{gm}^{c} and Π_t curves over some range of *A* making the production of the GM crop with purchased seed optimal for some producers.

Specifically, the intersection of Π_{gm}^{h} and Π_t in Figure 3 determines the level of the differentiating attribute that corresponds to the producer who is indifferent between producing a unit of the GM crop and a unit of its traditional counterpart, A_{gm}, i.e.,

$$A_{gm} : \Pi_{gm}^{h} = \Pi_t \Rightarrow A_{gm} = \frac{\left(p_{gm} - p_{gm}^{s}\right) - \left(p_t - p_t^s\right)}{\gamma - \phi}$$

Producers with $A \in [0, A_{gm})$ will prefer to produce the GM crop (either with purchased or illegally used seeds), while producers with $A \in (A_{gm}, 1]$ find it more profitable to produce the traditional crop.

Given the assumptions about the production and distribution of producers (i.e., unit production and uniform distribution), A_{gm} also gives the total supply of the GM crop, x_{gm}. The quantity of the GM crop being produced illegally, x_{gm}^{c}, is given by:

(5) $$x_{gm}^{c} = A_{gm}^{c} : \Pi_{gm}^{c} = \Pi_{gm}^{h} \Rightarrow x_{gm}^{c} = \frac{p_{gm}^{s}}{\delta_0 \rho}$$

while the supply of GM crop produced with purchased seed, x_{gm}^{h}, equals:

(6) $$x_{gm}^{h} = x_{gm} - x_{gm}^{c} = \frac{\delta_0 \rho \left[p_t^s - \left(p_t - p_{gm}\right)\right] - \left[\gamma - \phi + \delta_0 \rho\right] p_{gm}^{s}}{\delta_0 \rho \left(\gamma - \phi\right)}$$

If, on the other hand, the price of the new technology is such that $p_{gm}^{s} \geq \frac{\delta_0 \rho \left[p_t^s - \left(p_t - p_{gm}\right)\right]}{\left(\gamma - \phi + \delta_0 \rho\right)}$, all GM crop producers will find it economically optimal to use GM seeds illegally. The Π_{gm}^{h} curve lies underneath Π^{c}_{gm} and Π_t curves over all values of A (Figure 4) and there is no supply of GM crop produced with purchased seeds, i.e.,

(7) $$x^{h}_{gm} = 0$$

In this case, the supply of GM crop equals:

(8) $$x^{c}_{gm} = x_{gm} = A^{c}_{gm} : \Pi^{c}_{gm} = \Pi_t \Rightarrow x^{c}_{gm} = \frac{p^{s}_{t} - (p_t - p_{gm})}{\gamma - \phi + \delta_0 \rho}$$

3.2. Innovator's Problem

When enforcement of IPRs is exogenous to the innovator, the problem of the innovating firm can be seen as the determination of the price of the new technology (GM seed) that maximizes its profits given the level of IPR enforcement determined by the domestic government and the best response function of the producers (i.e., the demand for GM seed). Assuming fixed proportions between seed and farm output, the demand for GM seed is given by equation (6) (i.e., $x^{s}_{gm} = x^{h}_{gm}$), and the problem of the seed company can be written as:

(9) $$\begin{aligned} &\max_{p^{s}_{gm}} \ \pi = (p^{s}_{gm} - m) x^{s}_{gm} \\ &\quad s.t. \ \ x^{s}_{gm} \geq 0 \Rightarrow p^{s}_{gm} \leq \frac{\delta_0 \rho [p^{s}_{t} - (p_t - p_{gm})]}{\gamma - \phi + \delta_0 \rho} \end{aligned}$$

where all variables are as previously defined.

The problem specified in equation (9) is a simple, static optimization problem with a non-equality constraint. The non-equality constraint requires that the quantity of the GM seed should be non-negative. The Lagrangean of the innovator's problem is:

$$L = (p^{s}_{gm} - m) \frac{\delta_0 \rho [p^{s}_{t} - (p_t - p_{gm})] - [\gamma - \phi + \delta_0 \rho] p^{s}_{gm}}{\delta_0 \rho (\gamma - \phi)} + \lambda \left[\frac{\delta_0 \rho [p^{s}_{t} - (p_t - p_{gm})]}{\gamma - \phi + \delta_0 \rho} - p^{s}_{gm} \right]$$

while the Kuhn-Tucker conditions for a maximum are:

$$\frac{\partial L}{\partial p^{s}_{gm}} \leq 0, \qquad p^{s}_{gm} \geq 0 \quad \rightarrow \quad \frac{\partial L}{\partial p^{s}_{gm}} p^{s}_{gm} = 0$$

$$\frac{\partial L}{\partial \lambda} \geq 0, \qquad \lambda \geq 0 \quad \rightarrow \quad \frac{\partial L}{\partial \lambda} \lambda = 0$$

Solving the optimality conditions for p_{gm}^{s} shows that, for a given marginal cost of producing the GM seed and given prices of the traditional seed, the GM crop and the traditional crop, the innovator's pricing decisions depend on the level of IPR enforcement/IPR protection by the domestic government, $\delta_0\rho$. Specifically, if $\delta_0 \rho \geq \frac{(\gamma-\phi)m}{p_t^s-(p_t-p_{gm})-m}$, the intercept of the derived demand for GM seed faced by the innovator is greater than or equal to the marginal cost of production and the optimal price-quantity combination is determined by equating marginal revenues with marginal costs of producing the GM seed. Mathematically, the optimal p_{gm}^{s} equals:

$$(10) \qquad p_{gm}^{s} = \frac{\delta_0 \rho}{\gamma-\phi+\delta_0 \rho}\frac{\left[p_t^s-(p_t-p_{gm})\right]}{2}+\frac{m}{2}$$

and the equilibrium quantity supplied by the innovator is given by:

$$(11) \qquad x_{gm}^{s} = \frac{p_t^s-(p_t-p_{gm})-m}{2(\gamma-\phi)}-\frac{m}{2\delta_0 \rho}=\frac{\delta_0 \rho\left[p_t^s-(p_t-p_{gm})-m\right]-(\gamma-\phi)m}{2\delta_0 \rho(\gamma-\phi)}$$

Figure 5 graphs the determination of the equilibrium p_{gm}^{s} and x_{gm}^{s} when the level of enforcement is such that $\delta_0 \rho > \frac{(\gamma-\phi)m}{p_t^s-(p_t-p_{gm})-m}$. Recall that, under fixed proportions between seed and farm output, x_{gm}^{s} also gives the quantity of the GM crop produced with purchased seed, x_{gm}^{h}, while substituting the optimal p_{gm}^{s} into equation (5) gives the equilibrium quantity of GM crop that is produced with illegally used seed, i.e.,

$$(12) \qquad x_{gm}^{c} = \frac{\delta_0 \rho\left[p_t^s-(p_t-p_{gm})+m\right]+(\gamma-\phi)m}{2\delta_0 \rho(\gamma-\phi+\delta_0 \rho)}$$

Obviously, when $\delta_0 \rho < \frac{(\gamma-\phi)m}{p_t^s-(p_t-p_{gm})-m}$ the intercept of the derived demand for GM seed lies underneath the marginal cost of production. In this case, the profit-maximizing seed company will find it optimal to exit (not supply) this market since there is no quantity of x_{gm}^{s} that can generate positive profits, i.e.,

(13) $x_{gm}^{s} = 0$

When the innovator does not supply the domestic market, the net returns curve Π_{gm}^{h} becomes irrelevant (i.e., farmers have no choice of producing GM crop with purchased seed), and all GM crop is produced with illegally used seed, i.e.,

(14) $x_{gm}^{c} = x_{gm} = A_{gm}^{c} : \Pi_{gm}^{c} = \Pi_{t} \Rightarrow x_{gm}^{c} = \dfrac{p_{t}^{s} - \left(p_{t} - p_{gm}\right)}{\gamma - \phi + \delta_{0}\rho}$

Based on these results we can determine the consequences of imperfect IPR enforcement for the price and quantity of the GM seed, the adoption of the new technology, and the welfare of the interest groups. Specifically,

Proposition 2: IPR infringement reduces the price of the new technology and the quantity supplied by the innovator.

Proof: Written in inverse form, the demand curve for the GM seed under imperfect IPR enforcement (i.e., equation (6)) is:

(15) $p_{gm}^{s} = \dfrac{\delta_{0}\rho}{\gamma - \phi + \delta_{0}\rho}\left\{\left[p_{t}^{s} - \left(p_{t} - p_{gm}\right)\right] - \left(\gamma - \phi\right)x_{gm}^{s}\right\}$

Since, by assumption, $\gamma > \phi$, $\dfrac{\delta_{0}\rho}{\gamma - \phi + \delta_{0}\rho} < 1$ which implies that IPR infringement reduces the demand faced by the innovator. Graphically, cheating causes a counter-clockwise rotation of the derived demand for seed through the point at which the demand curve meets the horizontal axis (Figure 5). Since IPR infringement reduces both the intercept and the slope of the demand for GM seed, it reduces the profit maximizing price-quantity combination of the new technology. Specifically, comparing the equilibrium prices under perfect and imperfect enforcement of IPRs (equations (3) and (10), respectively) shows that IPR infringement reduces the price charged by the innovator by $\dfrac{\left(\gamma - \phi\right)\left[p_{t}^{s} - \left(p_{t} - p_{gm}\right)\right]}{2\left(\gamma - \phi + \delta_{0}\rho\right)}$. Similarly, the equilibrium supply of GM seed under imperfect IPR enforcement (equation (11)) is reduced relative to the quantity supplied under perfect enforcement (equation (4)) by $\dfrac{m}{2\delta_{0}\rho}$ (or, by $\dfrac{p_{t}^{s} - \left(p_{t} - p_{gm}\right) - m}{2\left(\gamma - \phi\right)}$ when $\delta_{0}\rho < \dfrac{\left(\gamma - \phi\right)m}{p_{t}^{s} - \left(p_{t} - p_{gm}\right) - m}$ and the innovator finds it optimal to exit this market).

Proposition 3: IPR infringement increases the adoption of the new technology by producers.

Proof: Aggregating the quantities of GM crop produced with purchased seed (equation (11)) and illegally used seed (equation (12)) shows that the total quantity of GM crop produced under imperfect enforcement of IPRs exceeds the quantity produced in the "perfect IPR enforcement" case (equation (4)) by $\frac{p_t^s - (p_t - p_{gm})}{2(\gamma - \phi + \delta_0 \rho)}$ (compare x_{gm} with x_{gm}^{pe} in Figure 6 where the superscript *pe* stands for perfect IPR enforcement). When $\delta_0 \rho < \frac{(\gamma - \phi)m}{p_t^s - (p_t - p_{gm}) - m}$ IPR infringement increases the total GM crop production by $\frac{(\gamma - \phi)[p_t^s - (p_t - p_{gm}) + m] - \delta_0 \rho [p_t^s - (p_t - p_{gm}) - m]}{2(\gamma - \phi)(\gamma - \phi + \delta_0 \rho)}$.

Following Propositions 2 and 3 we can determine the welfare effects of IPR infringement for the innovating firm and producers. Specifically,

Proposition 4: Imperfect IPR enforcement reduces the rents accruing to the innovator/IPR holder.

Proof: The reduced (derived) demand for the new technology (GM seed) faced by the innovator and the consequent reduced equilibrium price and quantity of GM seed when producers use GM seed illegally, cause innovator welfare to fall. The decrease in monopolistic rents accruing to the innovator equals $\Delta\pi = \frac{[p_t^s - (p_t - p_{gm})]^2}{4(\gamma - \phi + \delta_0 \rho)} - \frac{m^2}{4\delta_0 \rho}$ and is shown by the shaded area in Figure 5. Obviously, when $\delta_0 \rho < \frac{(\gamma - \phi)m}{p_t^s - (p_t - p_{gm}) - m}$ no GM seed is supplied and the entire monopolistic rent under perfect IPR enforcement goes unrealized – IPR infringement reduces then the rents of the innovator by $\Delta\pi = \frac{[p_t^s - (p_t - p_{gm}) - m]^2}{4(\gamma - \phi)}$.

Regarding the consequences of imperfect IPR enforcement for producers,

Proposition 5: IPR infringement increases the welfare of producers. It increases the welfare of producers that use the GM seed illegally and also the welfare of domestic producers that purchase the GM seed.

Proof: Imperfect enforcement of IPRs increases the welfare of producers that use the GM seed illegally by the shadowed area C in Figure 6. At the same time, IPR infringement creates a positive externality for producers that purchase the GM seed they use, through its effect on the price of the seed. Graphically, the reduction in p_{gm}^s when cheating occurs shifts the Π_{gm}^h curve upwards which increases producer welfare by the hatched area AC in Figure 6. Obviously, when

$\delta_0 \rho < \dfrac{(\gamma - \phi)m}{p_t^s - (p_t - p_{gm}) - m}$, the curve Π_{gm}^{h} becomes ineffective and the relevant net returns curve associated with the production of the GM crop is shown as $\Pi_{gm}^{c\_ne}$ in Figure 6. In this case, producer welfare gains from cheating are given by areas C+AC+NE in Figure 6.[7]

3.3. Government's Problem and Optimal Enforcement of IPRs

The analysis in the previous sections indicates that the pricing of the new technology and the amount of cheating depend on the level of IPR enforcement. This section of the paper determines the optimal decisions of the government that is responsible for the enforcement of innovator's IPRs.

The problem of the government/IPR enforcement agency is to determine the degree to which the IPRs are enforced, knowing exactly how its decisions will affect the behavior and welfare of the seed company and producers. The degree to which IPRs are enforced is determined by the detection probability and per unit penalty parameters. Penalties on detected illegal use of GM seeds are often set elsewhere in the legal system. With penalties being exogenous, the only avenue policy makers have for influencing the agents' behavior is through the choice of audit probability δ_0.

Specifically, the problem of the government can be seen as the determination of the audit probability that maximizes the country's welfare subject to a "minimum innovator rent" (*MIR*) constraint requiring that innovator rents do not fall below some minimum level, $\overline{IR}$, i.e.,

$$(16) \qquad \begin{aligned} &max_{\delta_0}\ W = PS - TC \\ &\quad s.t.\ \ IR \geq \overline{IR}(\geq 0) \end{aligned}$$

The parameters *PS*, *TC*, and *IR* stand for producer surplus, taxpayer costs, and innovator rents, respectively. Consumer surplus can be safely assumed away from the objective function of the government since, in the small open economy case, domestic enforcement and production decisions have no effect on the price of the final (GM or traditional) product.

Taxpayer costs are given by the costs associated with IPR enforcement, $\Phi(\delta_0)$, adjusted to account for the distortionary costs of taxation, i.e., $TC = (1+d)\Phi(\delta_0)$ (Fullerton, 1991; Ballard and

[7] While the analysis assumes that use of farmer-saved seeds is illegal, this might not necessarily be the case. When farmers are allowed to use seed harvested from the previous year's crop (e.g., case of Argentina), the analysis can be seen as applying to use of GM seed purchased from the black market. The implications of farmers' ability to legally use farmer-saved GM seeds are quite straightforward. Obviously, GM crop producers with access to saved seed will find it optimal to use it. Legal use of farmer-saved seeds increases producer surplus and the adoption of new technology while reducing the demand faced by the seed company, the price and quantity of the GM seed supplied in the developing country, and the rents accruing to the innovator/IPR holder.

Fullerton, 1992). Regarding producer surplus and innovator rents, they depend on the level of enforcement. Specifically, when $\delta_0 \rho \geq \frac{(\gamma - \phi)m}{p_t^s - (p_t - p_{gm}) - m}$, *PS* equals

$p_t - p_t^s + \frac{\gamma}{2} + \frac{\delta_0 \rho (B-m)^2 + 2(\gamma - \phi)(2B^2 - B + m)}{8(\gamma - \phi)(\gamma - \phi + \delta_0 \rho)} + \frac{(\gamma - \phi)m^2}{8\delta_0 \rho (\gamma - \phi + \delta_0 \rho)}$ and *IR* equal

$\frac{[\delta_0 \rho (B-m) - (\gamma - \phi)m]^2}{4\delta_0 \rho (\gamma - \phi)(\gamma - \phi + \delta_0 \rho)}$ where $B = p_t^s - (p_t - p_{gm})$. When, on the other hand,

$\delta_0 \rho < \frac{(\gamma - \phi)m}{p_t^s - (p_t - p_{gm}) - m}$ *PS* increases to $p_t - p_t^s + \frac{\gamma}{2} + \frac{B^2}{2(\gamma - \phi + \delta_0 \rho)}$ while *IR* fall to zero.

The Lagrangean of the government's problem specified in equation (16) is:

$$L = PS - TC + \lambda\left(IR - \overline{IR}\right)$$

while the Kuhn-Tucker conditions for a maximum are:

$$\frac{\partial L}{\partial \delta_0} \leq 0, \qquad \delta_0 \geq 0 \quad \rightarrow \quad \frac{\partial L}{\partial \delta_0}\delta_0 = 0$$

$$\frac{\partial L}{\partial \lambda} \geq 0, \qquad \lambda \geq 0 \quad \rightarrow \quad \frac{\partial L}{\partial \lambda}\lambda = 0$$

Proposition 6: The optimal enforcement of IPRs will be such that the *MIR* constraint always binds, i.e., the optimal audit probability will be such that innovator rents are equal to $\overline{IR}$.

Proof: Solving the optimality conditions for δ_0 shows that, for any minimum desirable surplus transfer to the innovator, domestic welfare is maximized when:

(17) $\delta_0 : \quad IR = \overline{IR}$

The reasoning of this result is as follows. Since δ_0 decreases domestic welfare (by decreasing producer surplus, $\frac{\partial PS}{\partial \delta_0} < 0$, and increasing the resource costs of IPR enforcement, $\frac{\partial \Phi(\delta_0)}{\partial \delta_0} > 0$), while increasing innovator rents, $\frac{\partial IR}{\partial \delta_0} > 0$, domestic welfare is maximized when enforcement is reduced at the level at which the surplus transfer to the innovator is minimized, i.e., $IR = \overline{IR}$.[8]

The same result also holds when penalties for IPR infringement are endogenous to the government, i.e., when the government has control over both δ_0 and ρ, enforcement is set so that $IR = \overline{IR}$. However, when the establishment of penalties is costless, the desired level of IPR enforcement can be achieved at zero cost. Specifically, since both audits and penalties are inversely related to the amount of GM crop produced with illegally used seed (i.e., $\frac{\partial x_{gm}^c}{\partial \delta_0} < 0$ and $\frac{\partial x_{gm}^c}{\partial \rho} < 0$), the government can substitute costly audits with costless penalties; it can set δ_0 equal to zero and increase penalties to the level at which the desired level of IPR enforcement is achieved, i.e.,

(18) $$\delta_0 = 0,\ \rho :\ IR = \overline{IR}$$

Obviously, since innovator rents depend on IPR enforcement, the lower is $\overline{IR}$, the lower is the level of IPR enforcement, and the more extensive is IPR infringement in the developing country.

Proposition 7: When the government does not consider the effect of its choices on innovator rents but, instead, is merely concerned with maximizing domestic welfare, its optimal choice is to completely allow unauthorized use of the GM seed.

Proof: Substituting $\overline{IR} = 0$ into the government's problem shows that domestic welfare is maximized when:

(19) $$\delta_0 = \rho = 0$$

When IPR infringement is allowed, domestic producer welfare is maximized (i.e., $PS = p_t - p_t^s + \frac{\gamma}{2} + \frac{\left[p_t^s - \left(p_t - p_{gm}\right)\right]^2}{2(\gamma - \phi)}$), and enforcement costs are zero. An interesting implication of

[8] An alternative formulation of the government's objective function could include *IR* as a direct argument. Specifically, the problem of the government can also be modeled as $max_{\delta_0} W = kIR + \theta PS - TC$ where θ and k are the weights placed by the government on *PS* and *IR*, respectively. Since enforcement decreases producer welfare while increasing both the welfare of the innovator and the enforcement costs, the optimal level of audits is determined by the relative weight placed by the government on the welfare of the interest groups and the size of enforcement costs, ψ, i.e., $\delta_0(k, \theta, \psi)$. In this case, for given market conditions, the greater is the weight placed by the government on *PS*, or/and the greater is the size of enforcement costs, or/and the lower is the weight placed on innovator rents, the lower is the level of enforcement (i.e., $\frac{\partial \delta_0}{\partial \theta} < 0$, $\frac{\partial \delta_0}{\partial \psi} < 0$ and $\frac{\partial \delta_0}{\partial k} > 0$).

this result is that when innovator welfare carries no weight for the domestic government, IPRs will not be enforced even if the innovator wishes to incur the monitoring costs (in which case enforcement is costless for the government). Lack of enforcement also maximizes the production of the GM crop, i.e.,

(20) $$x_{gm}\left(= x_{gm}^{c}\right) = \frac{p_t^s - \left(p_t - p_{gm}\right)}{\gamma - \phi}$$

indicating that zero enforcement will also be the optimal choice of the government that has as objective to maximize the adoption of the new technology.

Proposition 8: When the government wishes to transfer the maximum possible amount of profits to the innovator, IPRs will be perfectly enforced.

Proof: Since the value of *IR* is maximized under perfect enforcement of IPRs (Figure 2), the government will deter IPR infringement through the establishment of zero audits and infinite fines for producers caught violating the innovator's IPRs. Substituting $\overline{IR} = \frac{\left[p_t^s - \left(p_t - p_{gm}\right) - m\right]^2}{4\left(\gamma - \phi\right)}$ into the government's problem shows that domestic welfare is maximized when:

(21) $$\delta_0 = 0, \quad \rho = \infty$$

Because IPRs are perfectly enforced when innovator welfare is valued highly by the government, the production decisions by producers, the pricing of the new technology, and the welfare of the interest groups are those derived in Section 2.

Since the optimal amount of enforcement is determined by $\overline{IR}$, the question that naturally arises is what are the determinants of the size of the minimum desirable surplus transfer to the innovator. Factors affecting $\overline{IR}$ include (but are not limited to): (i) the political influence of the innovating firm in the developing country, (ii) the bilateral relationship with, and the fear of retaliation from, the country of origin of the innovating firm, (iii) the severity of the sanctions in case the developing country is successfully convicted for imperfectly enforcing the innovator's IPRs, (iv) the conjectures of the domestic government regarding the effect of its enforcement policy on the future development of (and domestic access to) new technologies,[9] and (v) the size of the enforcement costs. All these are factors that affect the

[9] If the government believes that its actions have no effect on innovators' future investment decisions (i.e., "too small to count"), it is less likely that IPRs will be enforced. The impact of domestic enforcement policy (and, thus, production decisions) on future development of new technologies depends on the size of the domestic market. The smaller is the domestic market, the smaller is the effect of government's enforcement decisions on *total* innovator rents, and the weaker will be the incentives for IPR protection.

importance being placed by the government on the welfare of the innovating firm and thus, the size of $\overline{IR}$.

Obviously, the greater is the political influence of the innovator, or/and the stronger is the relationship between the developing country and the country of origin of the innovating firm, or/and the greater is the likelihood that imperfect IPR enforcement will be detected and successfully convicted, or/and the greater is the severity of potential retaliatory sanctions, or/and the stronger is the belief of the government that extensive violation of IPRs will adversely affect the future development of new technologies (and domestic producer access to them), or/and the lower are the resource costs associated with IPR enforcement, the greater is $\overline{IR}$, and the greater is the level of IPR enforcement in the developing country.

In this context, given the developing countries' vocal opposition to the granting of IPRs for agricultural crops, the lack of an effective mechanism that will monitor IPR enforcement around the world, the lack of an agreement on the penalty associated with IPR violation, the small size of most developing economies, and the significant resource costs of monitoring farmers, the lax enforcement and widespread violation of IPRs in these countries should come at no surprise.

4. Extensions of the model

4.1. No Labeling of GM Products

Consider now the situation where the final (GM or/and traditional) products are not labeled. In this case, the GM crop and its traditional counterpart are marketed together and the price received by producers is the same regardless of which crop is produced – there is no price premium received by producers of the traditional crop i.e., $p_t = p_{gm}$ (Giannakas and Fulton, 2001). The lack of price premium for the traditional crop affects the quantitative nature of the results derived in sections Sections 2 and 3.

Proposition 9: When compared to the labeling case, no labeling of GM products increases the demand for GM seed by producers, x_{gm}^s, the price of the new technology charged by the innovator, p_{gm}^s, and the adoption of the new technology in the developing country, x_{gm}, no matter if enforcement of IPRs is perfect or not. When IPR enforcement is imperfect, no labeling increases both the supply of GM crop produced with purchased seed, x_{gm}^h, and the quantity of GM crop produced with illegally used seed, x_{gm}^c.

Proof: Substituting zero for $p_t - p_{gm}$ in equations (3), (4), (10), and (11) results in higher x_{gm}^s, p_{gm}^s, and x_{gm} under both enforcement scenarios considered herein. Specifically, in the benchmark case where enforcement of IPRs is perfect, no labeling of GM products increases x_{gm}^{s} (and x_{gm}) by $\frac{p_t - p_{gm}}{2(\gamma - \phi)}$ and p_{gm}^{s} by $\frac{p_t - p_{gm}}{2}$. When enforcement is imperfect, no labeling increases x_{gm}^{s} and p_{gm}^{s} by $\frac{(p_t - p_{gm})}{2(\gamma - \phi)}$ and $\frac{\delta_0 \rho (p_t - p_{gm})}{2(\gamma - \phi + \delta_0 \rho)}$, respectively. Finally, no labeling results in increased cheating and increased adoption of the new technology relative to the labeling case (i.e., x_{gm}^{c} and x_{gm} increase by $\frac{(p_t - p_{gm})}{2(\gamma - \phi + \delta_0 \rho)}$) and $\frac{[2(\gamma - \phi) + \delta_0 \rho](p_t - p_{gm})}{2(\gamma - \phi)(\gamma - \phi + \delta_0 \rho)}$, respectively).

Proposition 10: When compared to the labeling case, no labeling of GM products reduces the likelihood that the innovator will exit the market.

Proof: The level of IPR enforcement, $\delta_0 \rho$, required for the innovator to supply the market (i.e., for x_{gm}^{s}>0) is reduced from $\frac{(\gamma - \phi)m}{p_t^{s} - (p_t - p_{gm}) - m}$ under labeling of GM products, to $\frac{(\gamma - \phi)m}{p_t^{s} - m}$ in the no labeling case. Since no labeling reduces this critical level of enforcement, it increases the likelihood that a realized level of IPR enforcement will exceed the critical one, and, thus, the likelihood that the innovator will find it optimal to supply this market.

4.2. Enforcement is Endogenous to Innovator

The previous analysis and results are based on the assumption that enforcement of IPRs is the responsibility of the developing country's government. This section of the paper examines the situation where IPR enforcement is endogenous to the innovating firm. Two scenarios are examined. In the first scenario, the innovating seed company is responsible for auditing the producers but penalties are set in the developing country. In the second scenario, the seed company has control over both audits and the magnitude of fines on detected IPR violators.

Proposition 11: When the innovator is responsible for monitoring (auditing) the producers and penalties are exogenous, the optimal audit probability depends on the size of the enforcement costs. The greater are the resource costs of enforcing the IPRs, the lower is the optimal level of enforcement. When enforcement costs are relatively high, exit from the market (and no auditing) becomes the optimal policy of the firm.

Proof: Incorporating the resource costs of monitoring and enforcement, $\Phi(\delta_0)(= \psi \delta_0)$, into the innovator's objective function (i.e., equation (9)) and maximizing with respect to δ_0 shows that the optimal audit probability depends on the size of the enforcement costs ψ. Specifically, the optimality conditions indicate that if ψ is less than a critical value

$\psi^{+}\left(=\dfrac{\rho\left(p_{gm}^{s}-m\right)\left[\left(p_{t}^{s}-p_{gm}^{s}\right)-\left(p_{t}-p_{gm}\right)\right]^{2}}{(\gamma-\phi)^{2}\,p_{gm}^{s}}\right)$, the optimal audit probability equals $\delta_0=\sqrt{\dfrac{\left(p_{gm}^{s}-m\right)p_{gm}^{s}}{\psi\rho}}$. When, on the other hand, ψ is greater than (or equal to) ψ^{+}, the innovator will find it optimal to not supply this market (and $\delta_0=0$). In this case, the curve Π_{gm}^{h} becomes ineffective and the whole of the GM crop is produced with illegally used seed.

The situation is different when the innovator controls both the audit probability and the penalties charged on detected cheaters.

Proposition 12: When penalties are endogenous to the innovator, cheating is completely deterred through the establishment of enormous fines for producers caught violating the innovator's IPRs. In this case, the production decisions by producers, the pricing of the new technology, and the welfare of the interest groups are those under perfect enforcement of IPRs (described in Section 2).

Proof: Solving the problem of the innovating firm with respect to both δ_0 and ρ shows that innovator profits are maximized when δ_0 = 0 and $\rho = \propto$. In this case, $x_{gm}^{c}=0$, $p_{gm}^{s}=\dfrac{p_{t}^{s}-\left(p_{t}-p_{gm}\right)+m}{2}$ and $x_{gm}^{s}=\dfrac{p_{t}^{s}-\left(p_{t}-p_{gm}\right)-m}{2(\gamma-\phi)}\left(=x_{gm}^{h}\right)$.

Even though the possibility that the foreign innovating firm will be delegated the establishment of (severe) penalties for IPR violators is potentially conceivable, it is not particularly appealing. While innovators can (and do) lobby for increased fines for IPR infringement, the punishment of detected cheaters will most likely lie with the domestic government. In this case, unless the government of the developing country is forced to establish specific fines (which is the ambition of developed countries/members of the TRIPs agreement), the level of IPR enforcement will still be determined by the minimum desirable surplus transfer to the innovator, $\overline{IR}$ (i.e., $\rho:\ IR=\overline{IR}\ \forall\delta_0$). Specifically, if the government does not consider the effect of its choices on innovator welfare (i.e., if $\overline{IR}=0$), IPR infringement will go unpunished (i.e., $\rho = 0$), the innovating firm will find it optimal to exit this market and δ_0 =0 (from proposition 11, when $\rho = 0$, ψ^{+} falls to zero and $\delta_0=0$). Similarly, if the government desires to maximize innovator rents, it will severely penalize detected IPR violators (i.e., $\rho = \propto$), and IPRs will be perfectly and costlessly enforced (from proposition 11, when $\rho = \propto$, ψ^{+} rises to $\propto$, and

$$\delta_0 = \sqrt{\frac{\left(p^s_{gm} - m\right)p^s_{gm}}{\psi\rho}} = 0).$$

The perfect enforcement of IPRs through the establishment of enormous fines, however, raises the question as to whether large fines for IPR infringement are reasonable. The literature on the economics of crime provides some guidance and evidence on this issue. More specifically, it has been argued that severe punishment for minor law violations (i.e., Becker's (1968) "optimal fine" result) is neither costless, credible nor just. The imposition of disproportionate fines would likely offend the public sense of justice; in short, justice requires that the punishment fit the crime (Carr-Hill and Stern 1977; Stern 1978; Stigler 1970; Shavell 1987; Cowell 1990). If producer compliance through the establishment of enormous and costless fines is indeed infeasible, then violation of IPRs will always be an issue and should be incorporated into economic analysis.

5. Further Consequences of IPR Infringement

The previous findings regarding the consequences of IPR infringement can help explain differential pricing of new technologies by innovating firms in different markets around the world. Specifically,

Proposition 13: Different levels of IPR enforcement rationalize different prices for the same technology charged by innovators in different countries around the world.

Proof: It has been shown that the level of IPR enforcement is influenced by the importance being placed by the government/IPR enforcer on innovator rents and influences the demand for the new technology. The lower is enforcement, the greater is IPR infringement, and the lower is the demand for the new technology. The lower is the demand faced by the innovating firm, the lower is the price that maximizes its profits. Thus, differences in IPR enforcement in different countries result in, *ceteris paribus*, different prices set by the profit-maximizing innovator that can effectively price discriminate.

From Proposition 13 it follows that

Proposition 14: IPR infringement increases the competitiveness of domestic producers that utilize the new technology by placing foreign producers that comply with the provisions of innovator's IPRs at a cost disadvantage.

Proof: Since IPR infringement reduces the price of the new technology in the domestic country, the greater is the extend of IPR violation, the lower is the price of the new technology and the greater is the cost advantage of domestic producers relative to producers in countries where IPRs are more effectively enforced.

Therefore, the effect of IPR infringement on the welfare of producers that comply with the provisions of the innovator's IPRs depends on the market the "honest" producers operate. Infringement of IPRs benefits "honest" producers of the country where IPR enforcement is lax (by reducing the price they pay for the new technology) while placing producers at foreign countries with increased compliance (reduced cheating) at a cost disadvantage. Reduced enforcement and allowance of IPR infringement can thus be viewed as a strategic choice of governments aiming at providing a competitive edge to the domestic users of the new technology.

6. Summary and Concluding Remarks

The introduction of IPRs is one of the most notable features of agricultural biotechnology. So are growing concerns about the widespread infringement of IPRs in developing countries. This study develops a model of heterogeneous producers to examine the economic causes of IPR infringement and its consequences for the welfare of the interest groups and the pricing and adoption of a new technology (GM seed) in the context of a small open developing economy. Enforcement of IPRs, and pricing and adoption of the new technology are modeled as a sequential game between the government that enforces the IPRs, a foreign innovating firm that prices the GM seed, and the domestic producers who make the production and cheating decisions.

Analytical results show that producer compliance with IPR provisions is not the natural outcome of self-interest and complete deterrence of IPR infringement is not always economically optimal. IPR infringement affects the welfare of the interest groups (producers and innovators) and has important ramifications for the pricing and adoption of the new technology. Specifically, violation of innovator's IPRs reduces the price of the new technology. While the quantity supplied by the innovator falls with IPR infringement, the adoption of the new technology increases when producers use the new technology illegally. This is true no matter if the final GM (or/and traditional) products are labeled or not. The existing labeling regime does affect the quantitative nature of the results, however. In general, when compared to labeling, no labeling increases both the price and adoption of the new technology, while reducing the likelihood that the innovator will exit the market.

The reduced price of the new technology under imperfect IPR protection means that while IPR infringement reduces the rents accruing to the innovator/IPR holder, it increases the welfare of all developing country's producers - imperfect IPR enforcement increases the welfare of IPR violators and also the welfare of producers that purchase the GM seed they use.

Since IPR infringement increases the welfare of domestic producers while reducing innovator rents, the level of optimal enforcement is determined by the political preferences of the government. The lower is the importance the developing country's government places on foreign innovator rents, the lower is the level of IPR enforcement, and the lower is innovator's ability to obtain value for its biotech traits.

When the government does not consider the effect of its choices on innovator rents but, instead, is merely concerned with maximizing domestic welfare, its optimal choice is to leave IPR infringement unpunished. This is true even if enforcement costs are incurred by the innovator. The innovating firm's ability to obtain value for its biotech traits is then eliminated and, as a consequence, the firm exits this market. On the other hand, enforcement will be perfect when innovator welfare is valued highly by the government and/or when the innovating firm controls both audits and penalties for IPR infringement. While the investigation of producers by the innovating firm is possible, the delegation of domestic producers' punishment to a foreign firm is not very likely. When the innovating firm audits producers but penalties are set in the developing country, enforcement of IPRs is effectively determined by the domestic government.

Factors affecting the importance the domestic government places on innovator rents (and thus its optimal enforcement policy) include the political influence of the innovating firm in the developing country, the bilateral relationship with, and the fear of retaliation from, the country of origin of the innovating firm, the severity of the sanctions in case the developing country is successfully convicted for lax IPR enforcement, the conjectures of the domestic government regarding the effect of its enforcement policy on the future development of new technologies, and the size of the enforcement costs.

Different governments can be expected to have different attitudes towards innovator rents, and thus, different enforcement policies. Since the price of the new technology falls with the extent of IPR violation, differences in the level of IPR protection provide an alternative justification for (and explanation of) differences in the pricing of the new technology in different countries around the world – a strategy adopted by leading innovators in the sector. Consequently, IPR infringement increases the competitiveness of domestic producers that utilize the new technology by placing foreign producers that comply with the provisions of innovator's IPRs at a cost disadvantage. Lax IPR enforcement can thus be used strategically by governments aiming at increasing the competitiveness of their producers in the international arena.

Given the absence of an effective supranational monitoring agency and the lack of an agreement on the penalties associated with IPR violation, the benefits from IPR infringement rationalize the lax enforcement and widespread violation of IPRs in developing countries. In terms of the TRIPs agreement, it seems to be well understood that the outcome of the on-going negotiations on the magnitude of fines for IPR infringement will be critical for the future level of protection enjoyed by innovators/IPR holders. What needs to be understood equally well however, is that if IPRs are to be effectively enforced it is necessary for the TRIPs agreement to go beyond the norms of GATT.

Given that developing country's welfare gains from lax IPR enforcement exceed the innovator's losses, if the penalties determined under the TRIPs agreement follow the custom of retaliatory sanctions under the GATT and reflect losses to the innovator, they will be proved insufficient in providing adequate incentives for IPR protection. Unless the WTO manages through the TRIPs agreement to "exceed its limits" and establish an effective enforcement mechanism, enforcement of IPRs will remain imperfect and innovators' ability to obtain value for their biotech traits will still be limited. However, given the lack of a precedent and developing countries' opposition to IPRs, an agreement on the establishment of fines that would exceed innovator damages will not be easy.

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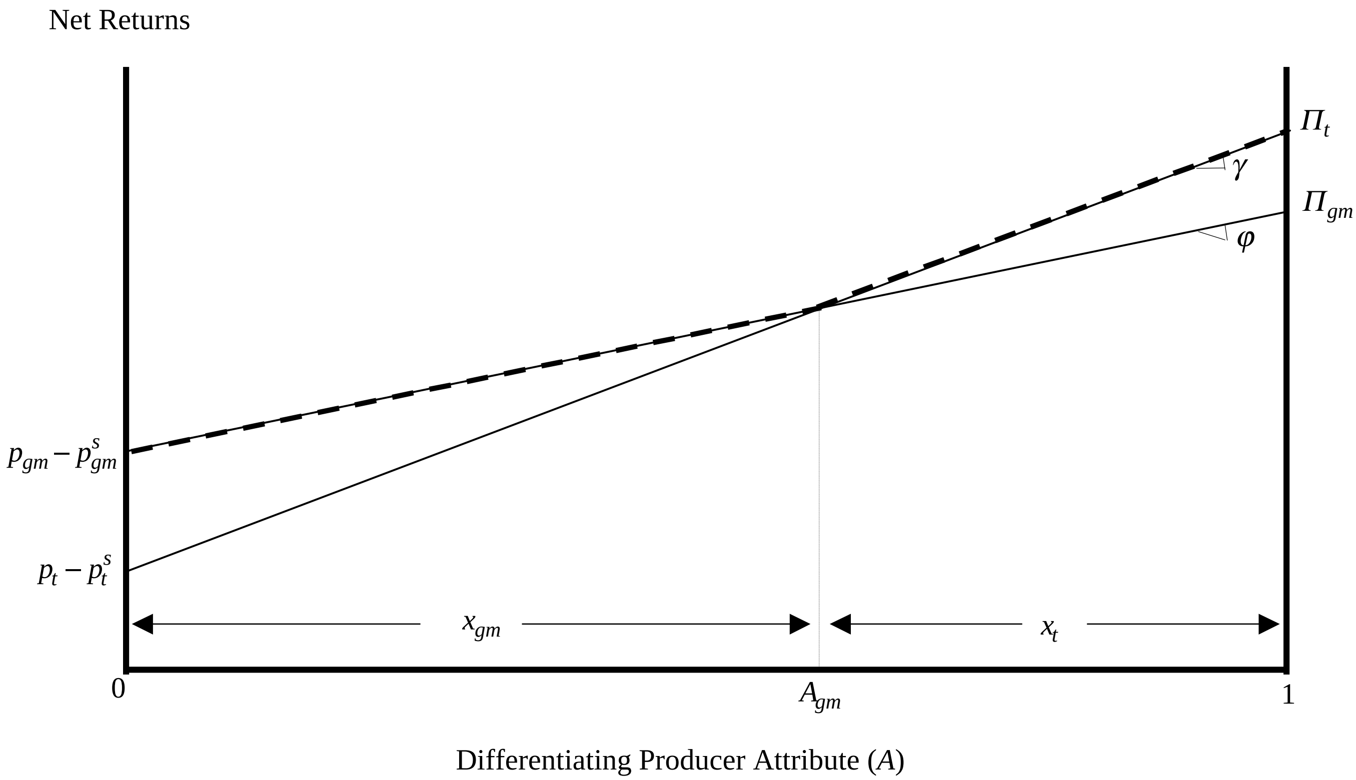

Figure 1. Production Decisions and Welfare under Perfect Enforcement of IPRs

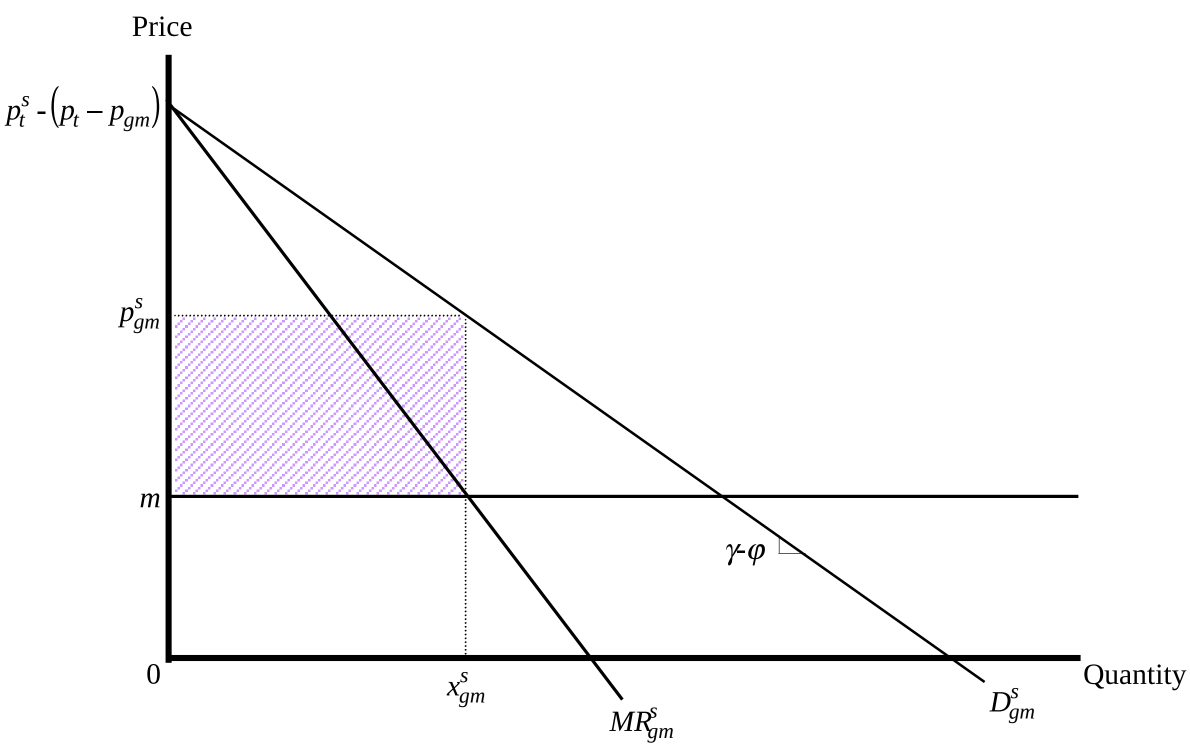

Figure 2. Production and Pricing of GM Seed under Perfect Enforcement of IPRs

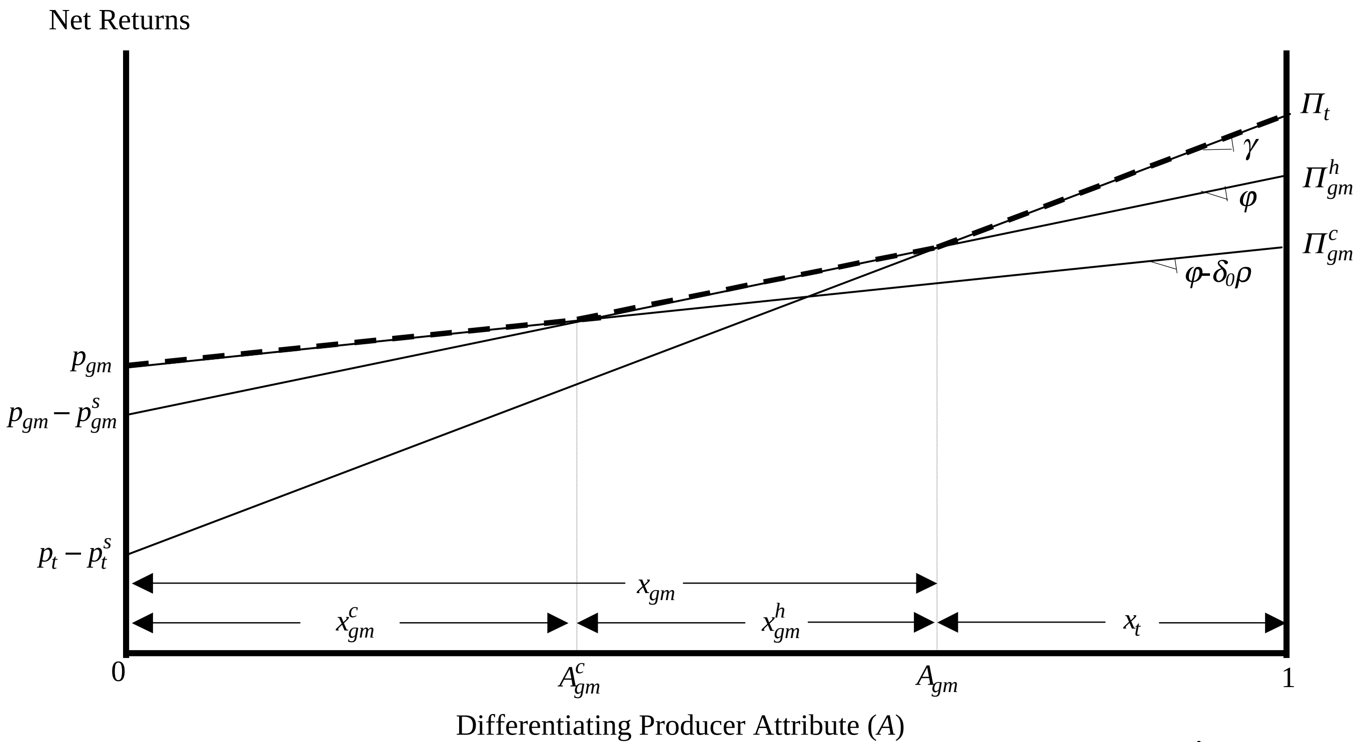

Figure 3. Production Decisions and Welfare under Imperfect Enforcement of IPRs ($p_{gm}^s < \frac{\delta_0 \rho \left[p_t^s - \left(p_t - p_{gm} \right) \right]}{\left(\gamma - \phi + \delta_0 \rho \right)}$)

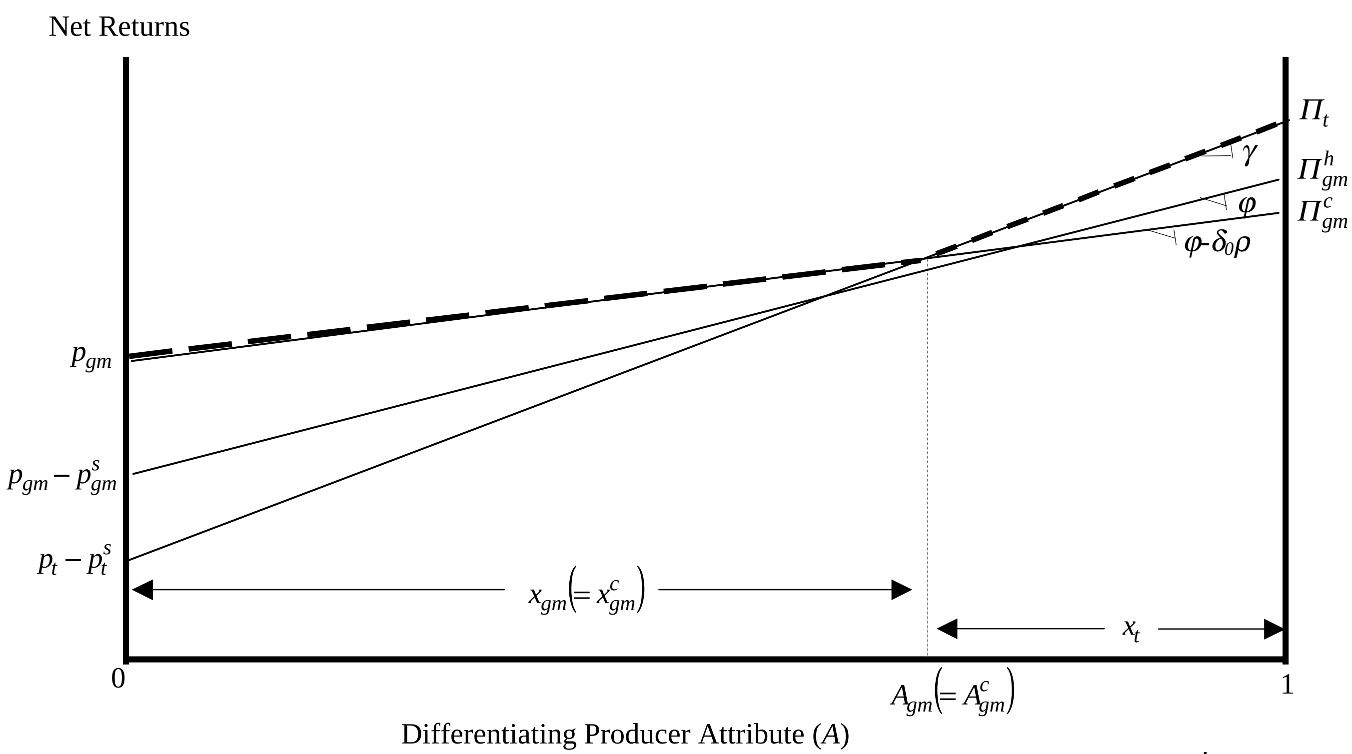

Figure 4. Production Decisions and Welfare under Imperfect Enforcement of IPRs ($p_{gm}^s > \frac{\delta_0 \rho \left[p_t^s - \left(p_t - p_{gm} \right) \right]}{\left(\gamma - \phi + \delta_0 \rho \right)}$)

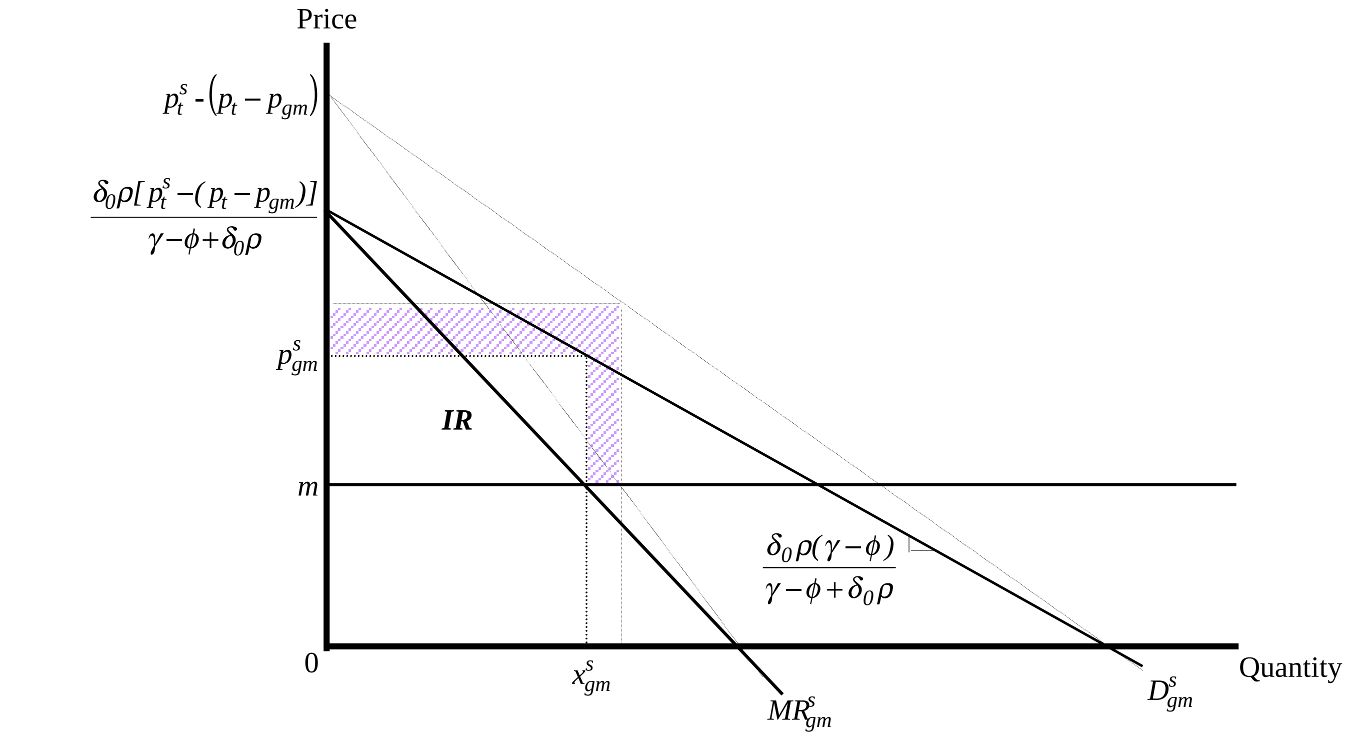

Figure 5. Production and Pricing of GM Seed and Innovator's Welfare Losses under Imperfect Enforcement of IPRs ($\delta_0\rho > \frac{(\gamma-\phi)m}{p_t^s - (p_t - p_{gm}) - m}$)

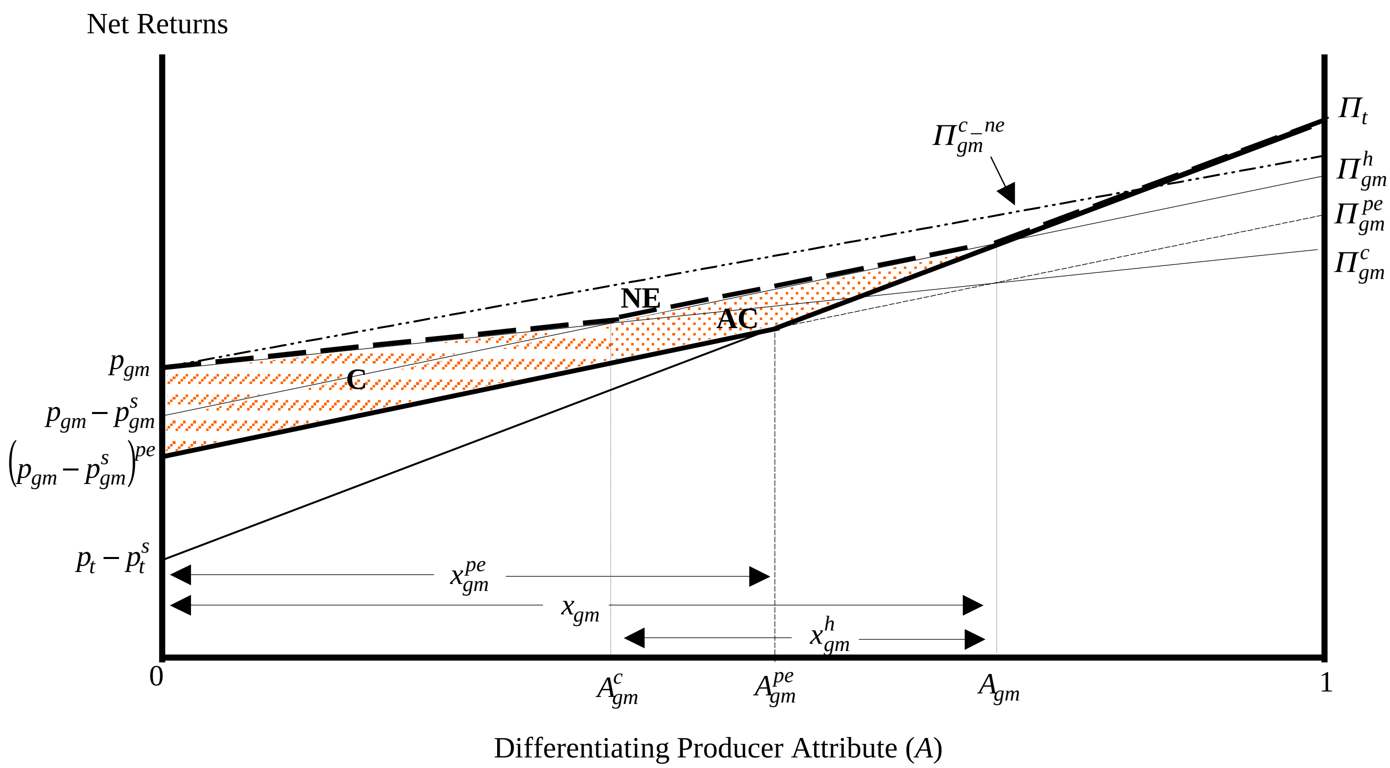

Figure 6. Production and Welfare Consequences of IPR Infringement ($\delta_0\rho > \frac{(\gamma-\phi)m}{p_t^s - (p_t - p_{gm}) - m}$)