[*Revised July 18, 2003*]

Regulation and enforcement of intellectual property rights for agricultural biotechnology in developing countries

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Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

REGULATION AND ENFORCEMENT OF INTELLECTUAL PROPERTY RIGHTS FOR AGRICULTURAL BIOTECHNOLOGY IN DEVELOPING COUNTRIES

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Game theory and numerical simulation are used to analyze government's role in regulating IPRs for agricultural biotechnology in a developing country. An imported variety brings productivity gains and a negative externality. The relative effectiveness of corrective taxes or subsidies depends upon whether there is full enforcement of the IPRs.

Key words: agriculture, biotechnology, enforcement, infringement, intellectual property rights, public policy, developing country

JEL Classification: D62, H23, L11, O34, Q16

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REGULATION AND ENFORCEMENT OF INTELLECTUAL PROPERTY RIGHTS FOR AGRICULTURAL BIOTECHNOLOGY IN DEVELOPING COUNTRIES

In a developing country, government policy plays an important role when agricultural biotechnology is introduced from abroad, such as when importing a genetically modified (GM) crop variety that has the potential to improve upon traditional varieties. The "host" government in a developing country may enable imports of a new GM variety and may allocate resources to the enforcement of the intellectual property rights (IPRs) that a foreign firm holds. In some cases, the host government may also choose to regulate the uses of the new technology, such as when adoption of the technology conveys positive or negative effects or externalties on the developing country's economy.

It is well established in the literature that numerous choices or tradeoffs may attend the government's decisions with respect to GM variety (Dutfield, Gaisford *et al*., Perrin). For example, a new variety may introduce both positive and negative externalities in addition to the productivity gains to be experienced by domestic producers. That is, there may be concern about public acceptance of the GM variety or concern about biosafety, human health effects or environmental threats to biodiversity. Conversely, there may be concern about the adequacy of financial incentives for foreign innovators to license their technology to the host country or for them to address that country's specific research needs. Commercial terms to license the technology may result in the repatriation of substantial royalties (monopoly rents) to innovators abroad. Consequently, host governments are positioned to play a strategic role in enforcing intellectual property rights (IPRs) and in controlling any externalities associated with the use of a new technology.

There is a growing literature that examines the welfare effects of alternative IPR regimes. Deardorff explores the issue of extending patent protection from the net-technology producing North to the net-technology consuming South and shows that effective IPR enforcement has a negative effect on the welfare of the South. Vishwasrao incorporates asymmetric information in a partial equilibrium, game theoretic setting to examine similar issues. Zigic, on the other hand, shows that in an applied duopoly model with technological spillovers, the South might not gain in terms of social welfare by relaxing IPRs. In a recent paper, Perrin argues that enforcement of IPRs in the Southern countries may be an answer to bridge the productivity gap between the North and the South.

This article builds upon recent game-theoretic analyses that model IPRs enforced by the host country when a foreign-owned monopolist introduces a new GM variety. Giannakas shows how a host government can, within limits, balance the competing interests of foreign rights holders and domestic crop producers by explicitly choosing to enforce the IPRs imperfectly. Strategic behavior by government allows the host country to capture some of the advantages of a new GM variety, and to experience lower GM seed prices than if IPRs were fully enforced. A more recent article (Chattopadhyay and Horbulyk) extends the analysis to include a new GM crop variety that also brings disadvantages to the adopting country. Since this GM variety brings some (perceived or actual) disadvantage, government's optimal policy response is also altered to include a corrective per unit tax on seed of the GM variety.

The current article models the strategic, sequential interaction of the host government, the foreign IPR holder, and domestic producers. The agents' interactions are modeled as a non-cooperative game in a small open economy. The principal development in this article is to expand the host country's public policy response to include either a form of corrective subsidy or a tax, and then to compare policy alternatives explicitly. Specifically, within a given IPR enforcement regime, government now introduces either an optimal per unit corrective subsidy on the traditional crop variety or it imposes an optimal per unit tax on the GM seed. The relative effectiveness of the two policy instruments is influenced by some producers' ability to infringe upon the IPRs on the GM variety without detection.

Closed-form analytical results describe the government's choice of the optimal tax or subsidy rates, where government strategically considers the behavior of both the foreign monopolist and the domestic producers if subject to the optimal tax or subsidy. In a static model with full information, the monopolist is expected to respond by adjusting market prices for GM seed, and (heterogeneous) domestic producers are expected to respond by choosing to cultivate larger amounts of either traditional varieties or the unlicensed GM variety. A series of cases is used to derive the optimal tax and subsidy rates and to compare the levels and distribution of social welfare under regimes with perfect versus imperfect enforcement of IPRs on the GM variety.

As anticipated, either the optimal tax or the optimal subsidy can raise host country welfare, yet, due to the presence of a foreign-owned monopoly, the “first best” outcome cannot be achieved by a single corrective tax or subsidy. If perfect enforcement of IPRs were possible, then either a tax on one variety or a subsidy on the other would lead to the “second best” outcome. However, under imperfect enforcement of IPRs, the use of an optimal tax is more effective at raising social welfare than is the optimal subsidy.

As the survey by Perrin shows, considerable attention is being paid to government’s role in the debates about IPRs, GM organisms and trade related IPRs (TRIPs). Whereas much of the earlier debate cast these choices as “all or nothing,” the current article identifies various margins of adjustment for public policy and compares relatively simple policy instruments in a complex strategic environment. The results of this article’s analysis support the implementation of public policy in a strategic manner that incorporates the optimizing behavior of all other agents.

The next section sets out the framework and key assumptions of the theoretical model recently presented by Giannakas. This model is then used to characterize behavior in each of six distinct cases. Whereas the first of these cases is essentially the same problem analyzed by Giannakas with specific modifications noted, the other cases build from that framework to address new issues. The analytical results are then compared and illustrated numerically, followed by conclusions.

Theoretical Model

Consider a developing country characterized by a small open economy in which three types of economic agents interact in the production of an agricultural crop for domestic and export use. Each type of agent will be described briefly.

Crop producers (producers, hereafter) form a heterogeneous group; differentiated by some productivity attribute such as farm location, soil characteristics or climate. Producers are risk-neutral and seek to maximize their expected short run profits by choice of a traditional or genetically modified crop variety best suited to their productivity attribute. Producers are price takers on input and output markets.

A foreign innovator (the monopolist, hereafter) holds the exclusive IPRs to import and to sell domestically the seeds for a GM variety of the crop. This GM variety offers increases in productivity and profit for some producers according to their differentiating attribute. The monopolist's objective is to maximize profits for its foreign-based shareholders by optimal choice of seed price for this GM variety. By assumption, the monopolist faces no costs to license, develop or adapt the GM variety to this market, and can replicate the GM seed for sale to producers at constant marginal cost.

The "host" government in this developing country (government, hereafter) seeks to maximize the contribution to domestic social welfare that comes from production of this crop. The principal contribution of crop production to social welfare comes in the form of producers' surplus. However, social welfare, and thus government action, will also be influenced by any "production externalities" and by the operation of the government's regulatory and enforcement activities with respect to IPRs, especially if these activities use resources or attract fiscal returns from abroad, for example. The government is cognizant that the monopolist requires some threshold level of short-run profits (possibly zero) to continue to offer the GM variety for sale domestically.

The form of the negative externality considered here is any social cost that increases in proportion to the quantity of the seeds of the GM variety that are purchased and planted. This form of externality is sufficiently general to encompass crop-specific effects such as perceived risks to other agricultural production activities, environmental concerns such as about biosafety and potential loss of biodiversity, or concerns by domestic residents about the GM crop's use that are not otherwise reflected in its price.

A GM crop variety might or might not be vulnerable to IPR infringement (i.e., unlicensed use). Two distinct regimes are considered and these affect government's role. Under one regime, producers find ways to gain the benefits of the GM variety without purchasing seed from the monopolist, such as when producers save seeds from a prior crop in violation of the IPR. For a crop variety vulnerable to infringement, government is able to restrict but not eliminate such infringement through implementing an enforcement program that expends public resources and earns public revenue from fines. By assumption, the scope and effectiveness of the enforcement program is taken as given by government, and might be determined by such factors as the type of crop in question or the general state of public enforcement infrastructure in the country.[1] Under the other regime, costless and perfect enforcement of the IPR is possible; such as when the GM variety incorporates a so-called "terminator gene" which makes it not possible for producers to save viable seeds. Notice that, in this small open economy where crops are tradable at fixed world prices, if government policy influences a producer's choice of the traditional versus GM variety, this does not directly influence consumers or any measure of domestic consumers' surplus.

The economic environment in which these three agents interact is characterized by full information about all other agents' objectives, choices and expected payoffs. Where governments enforce against producers who infringe the IPRs of the GM variety, the expected probability of a producer paying a given fine is known, ex ante, and thus there is a basis for all agents to predict accurately what fraction of producers will infringe. Interactions among agents take place once, within a static model of economic behavior, and are characterized by distinct short run equilibria in the markets for traditional and GM varieties of a single crop.

The strategic element of agents' behavior is illustrated in Figure 1, where a sequence of decisions is envisioned, and where all previous moves are fully observed before the next move is chosen. The agents' interaction is shown as a non-cooperative game in extensive form, which can be analyzed by backward induction. Since each agent's action fully anticipates the optimal and fully informed responses of other agents' whose actions follow, there is no role for non-credible threats. The result is a sub-game perfect Nash equilibrium.

According to the figure, in each case where a genetically modified crop is introduced to the developing country, a distinguishing and exogenous characteristic is whether or not its IPR can be fully and costlessly enforced. By assumption, only the GM crop variety will be associated with a production externality that affects domestic social

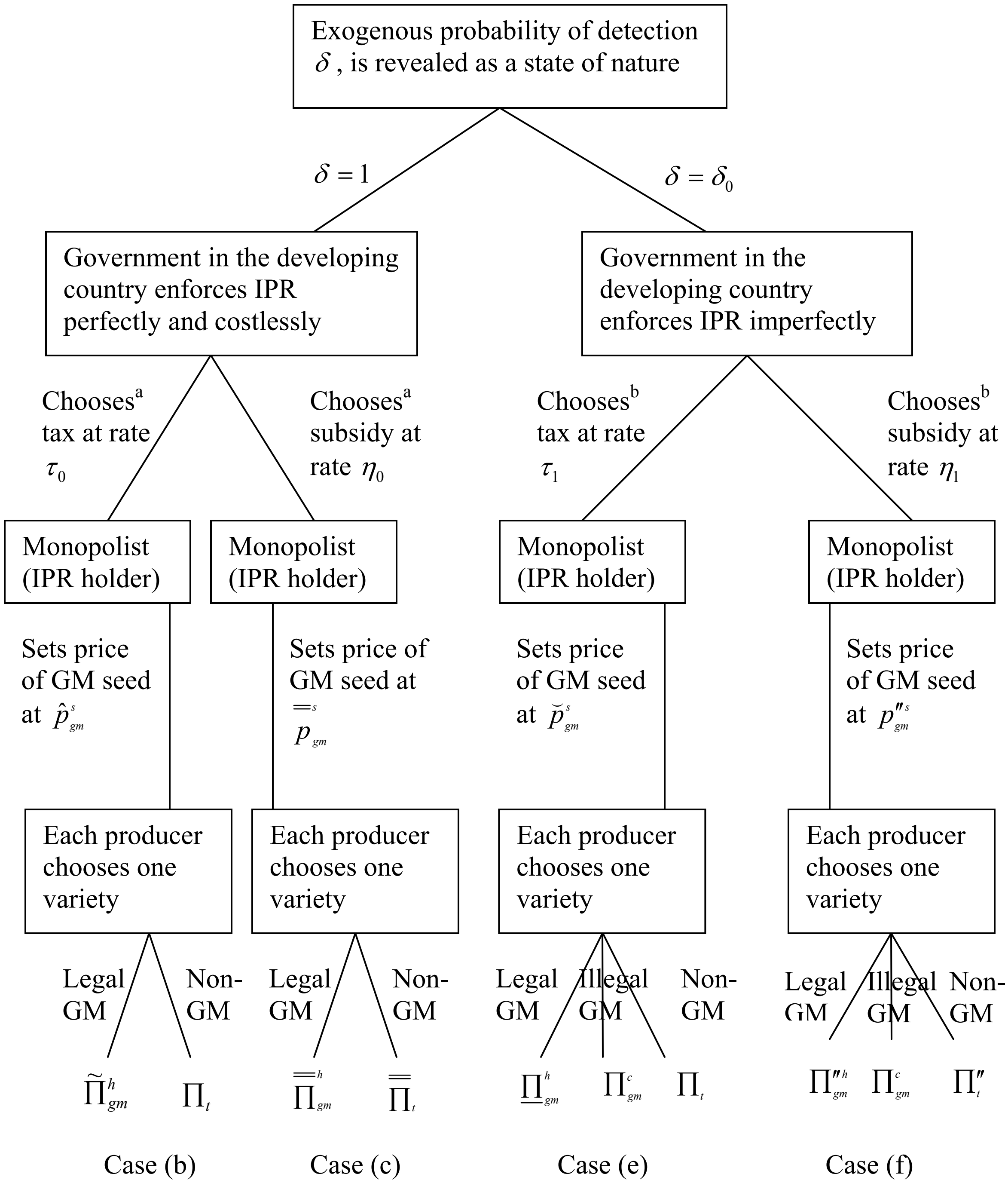

Figure 1. Game tree showing net returns to producers (Π) when government uses a tax or a subsidy to address the negative externality with GM variety

[a] In case (a), $\tau_0 = \eta_0 = 0$ under perfect enforcement

[b] In case (d), $\tau_1 = \eta_1 = 0$, under imperfect enforcement

welfare. If government has a public policy instrument to address the externality associated with the GM variety, then that instrument will be a per unit (or excise) tax on seeds of the GM variety, or a per unit subsidy on seeds of the traditional variety. Each producer chooses one crop variety acknowledging any differences in relative prices for the (GM versus traditional) seeds and crop outputs, especially as influenced by the rate of any corrective tax or subsidy.

Agents' Optimizing Behavior Under Six Alternative Assumptions

Agents' behavior and the resulting levels of social welfare can be examined in each of six cases that are identifiable from Figure 1. The first three cases relate to the left-hand side of the figure, where costless and full enforcement of the IPR is possible. Case (a) describes the situation with no public policy toward the externalities associated with the GM variety. Cases (b) and (c) describe the situations where the government chooses an optimal rate of corrective tax or subsidy, respectively. The last three cases address the right-hand side of the figure, where enforcement of the IPR is costly yet results in some exogenously determined degree of infringement. Case (d) describes the situation with no public policy (other than IPR enforcement) toward the externalities associated with the GM variety. In case (e), the government chooses an optimal rate of corrective tax on some GM seeds, yet cannot impose this tax on those seeds acquired by producers who are circumventing the IPR. In case (f), a subsidy is offered on purchases of traditional seeds.

An important determinant of the behavior of heterogeneous producers will be each's distinguishing production attribute, A. As in Giannakas, assume that each producer has a unique value of A drawn from a uniform distribution on the interval

$0<A<1$. For illustrative purposes, imagine A to be the degree of resistance of each producer's crop to (partial) yield losses due to frost, drought, soil salinity or pests. In the short run, that degree of resistance, A, is a fixed and observable artifact of each producer's arable land base. Imagine that, for a given crop, biotechnology has created a GM variety that can decrease this crop's vulnerability, thereby increasing yield for a given value of A. *Ceteris paribus*, producers with high A values will find crop production to be more profitable even without the GM variety, and producers with low A values will gain relatively more from adopting the GM variety.

In the short run, a producer's choice of crop variety will be governed by maximization of a short run profit function or net returns function. Fixed costs, capital investments (including other investments in A especially), and entry or exit possibilities are not relevant in the short run. Allowing that other crop choices require some specialized (human or physical) capital, in the short run producers are committed to producing this crop, if any, and will consider available varieties.

Case (a): No infringement of IPRs, no corrective policy to address the externality

In case (a), producers have a choice of producing the traditional or the licensed variety of this crop, since perfect enforcement of IPRs eliminates access to unlicensed (illegal) seeds of the GM variety. Define $\prod_t$ to be the net returns earned by producers while producing a unit of traditional crop; p_t, to be the farm price of the traditional crop (net of all production costs except for seed) and p_t^s, to be the price of traditional seed. Thus, equation (1) describes a producer's net returns for a unit of traditional crop production

(1) $$\prod_t = p_t - p_t^s + \gamma A.$$

The variable $\prod_{gm}^{h}$ denotes the net returns to producers of the GM crop variety, where p_{gm} is the farm price of GM output (net of all production costs except for seed) and p_{gm}^{s} is the price of the GM seed. Equation (2) gives the net returns for a unit of GM crop produced using licensed or legally acquired seed

(2) $$\prod_{gm}^{h} = p_{gm} - p_{gm}^{s} + \phi A.$$

Producers' resistance to production risks and yield losses, as reflected in the production attributes, *A*, affects the crop returns through the parameters $\gamma > \phi > 0$. As in Giannakas, to ensure that producers face a meaningful choice of the two available crop varieties that results in some of each being chosen, the pricing and productivity characteristics of the two crops must be such that

(3) $$(\gamma - \phi) > [(p_{gm} - p_{gm}^{s}) - (p_{t} - p_{t}^{s})] > 0.$$

This condition states that, in order for neither variety to dominate the entire seed market, the GM crop must be profitable for producers who are inherently most vulnerable to yield losses (low *A* values), but that the advantage of the GM crop must dissipate for those producers whose *A* values already reflect high resistance to yield losses.

Figure 2 illustrates the two crops' relative profitability as viewed by heteroge-neous producers. Equations (1) and (2) are plotted with (A, Π) coordinates as straight lines whose right-hand vertical intercepts are labeled $\prod_{t}$ and $\prod_{gm}^{h}$ respectively. The restriction (3) ensures that the (left-hand) vertical intercepts and slopes are such as to cause an intersection of (1) and (2) for some value of *A*. Their intersection defines the value A_{gm}, which is the critical or threshold value of *A*, below which producers find the GM seeds to

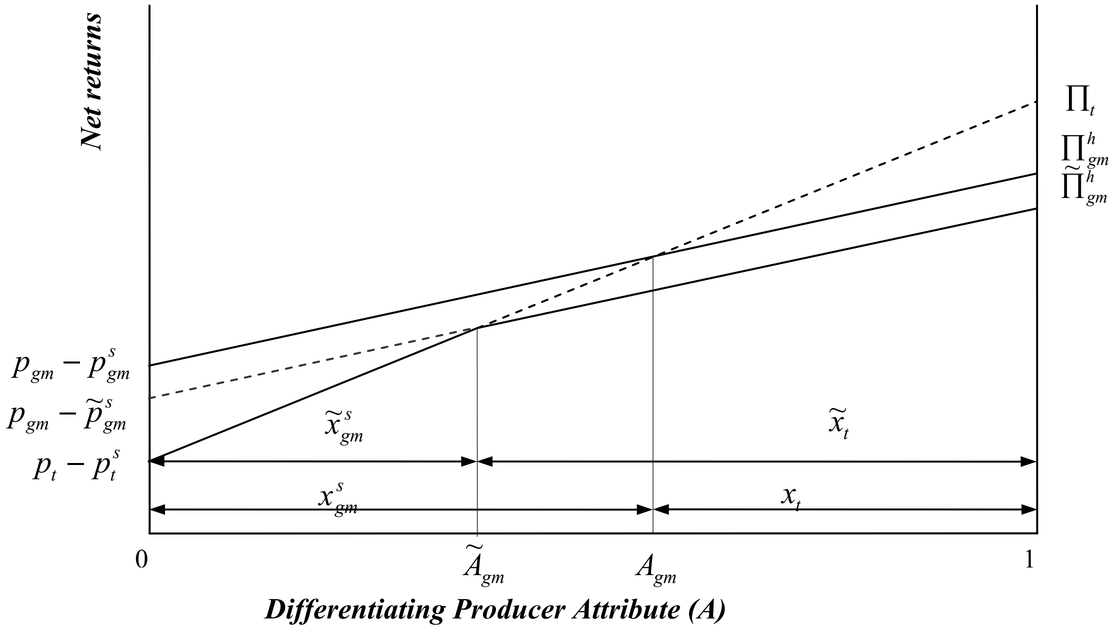

Figure 2. Producers' decisions and net returns under perfect enforcement of IPRs with and without a tax on GM seed, cases (a) and (b)

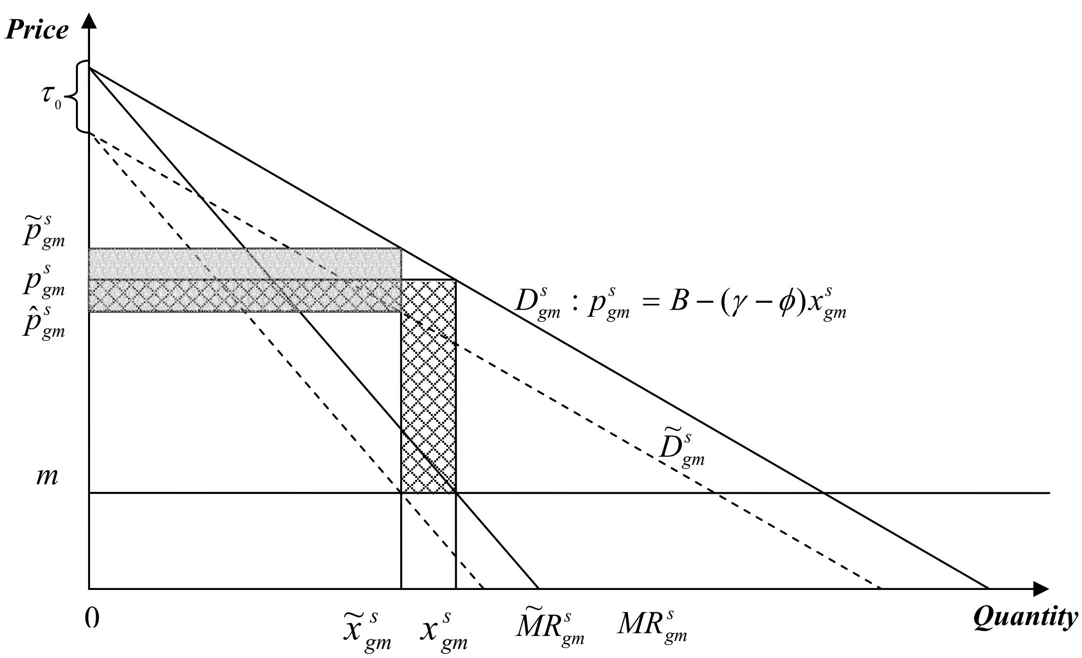

Figure 3. Optimal price and quantity of GM seed under perfect enforcement of IPRs, and loss in monopolist's rent due to taxation, cases (a) and (b)

be more profitable in the short run. The figure also shows that if GM seeds were to have a higher price, $\tilde{p}^{s}_{gm}$, then net returns, $\tilde{\Pi}^{h}_{gm}$, would be lower, and in equilibrium fewer producers (fraction $\tilde{A}_{gm}$) would choose the GM variety. This choice will be relevant to case (b) where a tax is introduced.

It will be useful to describe the quantities of GM seed that are associated with the fractions of producers (such as A_{gm} or $\tilde{A}_{gm}$) that choose the GM seed variety. Since the net returns (1) and (2) that define A_{gm} are expressed per unit of crop production, and since all of the producers have been distributed uniformly along the segment [0, 1] (by assumption), appropriate definition of units of measure for seed will assure that the value A_{gm} equals the quantity of GM seeds purchased, x^{s}_{gm}.[2]

The monopolist's problem is to set a price for GM seeds that will maximize short run profits. By assumption, the monopolist faces constant short run marginal costs, denoted m. This problem can be formally stated as[3]

(4) $$\max_{p^{s}_{gm}} \pi = (p^{s}_{gm} - m) \quad x^{s}_{gm}$$

where, with A_{gm} equal to x^{s}_{gm}, one may solve for the equilibrium price and quantity of GM seed. This solution can be used to derive the monopolist's (linear) demand curve, given by: $p^{s}_{gm} = p_{gm} - p_{t} + p^{s}_{t} - (\gamma - \phi)x^{s}_{gm}$. For notational simplicity, the intercept will be denoted by $B = (p_{gm} - p_{t} + p^{s}_{t})$ throughout.

The government does not take any policy action in case (a) and the level of domestic social welfare generated in case (a) from production of the two crop varieties is defined as the benchmark level. This level of social surplus consists of the producer's surplus earned less the cost of the negative externality which accompanies the GM variety and which is borne by domestic residents. Since all producers are uniformly distributed along the horizontal axis of Figure 2, by assumption, the total of their surplus is given by the area under the relevant line segments. Thus, producers' surplus is

$$(5) \qquad PS_a = \int_0^{A_{gm}} \prod\nolimits_{gm}^h dA + \int_{A_{gm}}^1 \prod\nolimits_t dA \;= p_t - p_t^s + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma-\phi)}.$$

Define the per period monetary value of the negative[4] effects or damages of GM seed use to be $D_a^{PE} = cx_{gm}^s$ where c is a constant ($0 < c \leq 1$). Therefore, in this case (a), social welfare (W_a) is

$$(6) \qquad W_a = PS_a - D_a^{PE} = p_t - p_t^s + \frac{\gamma}{2} + \frac{(B-m)^2}{8(\gamma-\phi)} - \frac{c(B-m)}{2(\gamma-\phi)} \quad .$$

Implicit here is the assumption of a strict utilitarian social welfare function where gains in this sector are separable from those in other sectors.

For each of the six cases under study, the short run equilibria in the economy can be characterized by the government's optimal tax or subsidy rate, if any, by the monopolist's optimal price and quantity for GM seeds, and by the resulting fractions of producers choosing each crop variety. One can then describe analytically the level and distribution of social welfare as evaluated at these optimal values. Table A1 in the Appendix collects these results, and Table 1 (below) will provide a numerical illustration.

Case (b): No infringement of IPRs, new corrective tax to address the externality

To address the negative externality that accompanies the GM variety, the government proposes a corrective tax to be levied on a per unit basis on producers' purchases of the GM seed. Under specific assumptions that do not hold here, a fully corrective (Pigovian) tax that was levied at a rate to match an activity's marginal external cost could offset the externality and return the market allocation to Pareto optimality. In cases (a) and (b) the exercise of monopoly power by the monopolist, with or without a tax, will necessarily frustrate attempts by the government to reach a Pareto optimal outcome by use of a single tax instrument. In cases (d) through (f), the inability to prevent infringement of the IPR makes the government's task even more difficult. Thus, in cases (b), (c), (e) and (f), the government's search for an optimal rate of tax or subsidy can at best lead to a constrained or "second-best" outcome in these markets (see Kolstad, p.129).

Suppose the government contemplates a tax at rate τ_0. This will raise the tax-inclusive price of GM seed to $\tilde{p}^s_{gm}$ (where $\tilde{p}^s_{gm} = \hat{p}^s_{gm} + \tau_0$ and where $\hat{p}^s_{gm}$ is the monopolist's price) and lower the profitability of using the GM seed to

$$(7) \qquad \tilde{\Pi}^h_{gm} = p_{gm} - \tilde{p}^s_{gm} + \phi A .$$

Figure 2 shows that producers would respond to the higher GM seed price by choosing not to produce as much of the GM variety. Strictly speaking, many producers' crop choice could be unaffected by the higher (tax inclusive) price, though their net returns would fall, but those with values of A between A_{gm} and $\tilde{A}_{gm}$ would switch varieties in response to the tax.

Following the approach of backward induction for case (b), the monopolist sees the market demand curve for GM seeds moving leftward for positive rates of tax, and lowers the market price accordingly. Re-solving the monopolist's profit maximization problem will cause the monopolist to lower the (optimized) price of the GM seed variety by one-half the rate of tax per unit, ($\tau_0 / 2$) and will therefore raise the tax-inclusive price faced by the producers by the same amount. This behavior is illustrated in Figure 3.

In case (a), optimizing producers had established a maximum (marginal) willingness to pay for the GM seeds, given their productivity attribute, *A*, and the relative prices of traditional seeds and output. That willingness to pay is still valid on a tax-inclusive basis and is shown by the curve D^s_{gm}. On a pre-tax basis, their maximum (marginal) willingness to pay for the GM seeds is lower by the amount of the tax. With linear demand curves and constant marginal costs, *m*, the static incidence of the tax is shared equally between the buyers and the seller in this market. Figure 3 also illustrates the fall in the monopolist's (innovator's) rent by the 'L' shaped hatched area shown in the figure. The rectangular area (shaded gray) is the tax revenue earned by the domestic government in the process.

In case (b), the government's problem is to choose the optimal rate of corrective tax (τ_0^*) to maximize social welfare, W_b, which consists of producers' surplus (PS_b) less negative externalities arising from biotechnology (D_b^{PE}) plus the tax revenue (TR_b). To ensure that the monopolist continues to sell output in the short run, it is necessary to ensure that the monopolist's profit (*IR*) is at or above some threshold level, possibly zero. Expressions for each of these terms appear in Table A1, so that social welfare is

$$(8) \qquad W_b = PS_b - D_b^{PE} + TR_b = p_t - p_t^s + \frac{\gamma}{2} + \frac{(c+m-B)^2}{6(\gamma-\phi)} .$$

Case (c): No infringement of IPRs, new corrective subsidy to address the externality

Another relatively simple policy instrument to address the negative production externality is a per unit corrective subsidy to be offered on purchases of the traditional seed variety.[5] Since, by assumption, in the short run there is a limited number of producers choosing this crop, if more choose the (subsidized) traditional variety there will be less production of the GM variety and less of its external cost borne domestically.

For a subsidy paid at rate η_0 on traditional seeds that are supplied competitively in the domestic market, the price of traditional seed drops to $(p_t^s - \eta_0)$, and the producers' net returns function for the traditional crop becomes

$$(9) \qquad \overline{\overline{\Pi}}_t = p_t - (p_t^s - \eta_0) + \gamma A .$$

This decrease in the domestic price of traditional seed causes a decrease in demand for GM seed. The monopolist would therefore choose a lower price and quantity than without the subsidy. Diagrammatic analysis of the producers' crop choice decision would proceed as described in Figure 2, with these exceptions. The net returns function for the GM variety would shift upward parallel, since the price has fallen, but the net returns function for the traditional variety would shift upwards farther, due to the subsidy. The resulting equilibrium allocation to the GM variety would decrease.

Government's choice of an optimal corrective subsidy rate, η_0^*, would be based on maximization of a social welfare function (W_c) that consists of producers' surplus (PS_c), minus externalities D_c^{PE} minus the subsidy payment made to the traditional seed suppliers (Pa_c). The values of these terms appear in Table A1, and support a level of W_c

$$W_c = PS_c - D_c^{PE} - Pa_c = p_t - p_t^s + \frac{\gamma}{2} + \frac{(c+m-B)^2}{6(\gamma-\phi)} \tag{10}$$

Case (d): Infringement of IPRs, no corrective policy to address the externality

In the absence of any technology such as a "terminator gene," there is, by assumption, the opportunity for some producers to infringe the monopolist's IPR on a given crop variety by acquiring the seeds without paying any price. Treating these "free" GM seeds as a "variety," then the producers face a third "variety" choice, x_{gm}^c, and associated expected net returns function $\prod_{gm}^c$ given by

$$\Pi_{gm}^c = p_{gm} + \phi A - \delta(A)\rho \,. \tag{11}$$

Here $\delta(A)$ is the probability of the developing country government identifying "cheating" (infringement) on the part of some producers, with ($0 \leq \delta \leq 1$), and ρ is the fixed (per unit) penalty imposed (with certainty) on those producers who are caught. The value of δ depends upon the probability that the producers will be audited (δ_0) and the producer- specific characteristics, denoted by the differentiating attribute A. For simplicity, similar to Giannakas, a linear function is assumed to relate δ, δ_0 and A, i.e., $\delta = \delta_0 A$. In the present study, for analytical purposes, δ_0 is assumed to be fixed.

The monopolist chooses a lower optimal seed price, $\overline{p}^{s}_{gm}$, when the IPRs are not fully protected. Analyzing a similar case with an endogenous probability of detection, Giannakas (p. 485) shows that risk-neutral producers in this environment would choose the illegal seed whenever the market price of the GM seed is greater than the expected penalty from cheating.

The enforcement cost to government of reducing IPR infringement (EC hereafter) is assumed to be an increasing function of the (exogenous) detection rate

(12) $$EC = \alpha\delta_0 + \beta \qquad \alpha > 0, \quad \beta > 0\,.$$

Expected public revenue from the penalty (F_d) can be thought of as a function of the producers' probability of getting caught while cheating ($\delta_0 A$) and the penalty (ρ),

(13) $$F_d = \rho \int_0^{A^c_{gm}} (\delta_0 A)\,dA\,.$$

As in cases (a) and (b), the producers' optimizing choices of crop variety will sort the producers into three groups according to increasing values of their productivity attribute, *A*. Those producers with the lowest attribute values will find it most profitable to infringe and to risk enforcement penalties. Those with higher values will acquire the GM seed legally, whereas those with the highest *A* values will produce the traditional variety.

Here, in case (d), the government implements no active policy with respect to external effects of GM crops. Government implements the passive, costly and imperfect enforcement program to protect the monopolist's IPRs from infringement and collects for its own use the revenue from fines. Note that the valuation of the negative externality in this case now incorporates both legal and illegal components of GM seed usage, such that

(14) $$D_d^{IE} = c(x_{gm}^h + x_{gm}^c).$$

This implies that the damage caused under the imperfect enforcement scenario is more than that under the perfect enforcement scenario provided that $(x_{gm}^h + x_{gm}^c) > x_{\underset{gm}{}}^s$.

Government is a passive observer of the social welfare level, W_d, given by

(15) $$W_d = PS_d - D_d^{IE} - EC + F_d = p_t - p_t^s + \frac{\gamma}{2} - (\alpha\delta_0 + \beta) + \frac{m^2}{4\delta_0\rho} - \frac{B^2(\gamma-\phi)}{8(\gamma-\phi+\delta_0\rho)^2} - \frac{(B-m)(4c+m-B)}{8(\gamma-\phi)} - \frac{B(2c-m-2B)}{4(\gamma-\phi+\delta_0\rho)}.$$

Case (e): Infringement of IPRs, new corrective tax to address the externality

In this case, the government's attempts to control a negative externality using a corrective tax are made more difficult (than in case (b)) by the government's inability to charge or to collect a tax on those producers who would infringe the monopolist's IPR. Those producers who are caught under this regime of imperfect enforcement will pay a fine, but not the tax. (Although some jurisdictions' penalties for sales tax evasion require payment of the evaded tax, here there is no attempt to tax infringing producers on GM seed purchases they did not make.)

In case (e), both the tax and imperfect enforcement act to reduce market demand. Denoting the monopolist's price here as $\breve{p}_{gm}^s$ gives $\underline{p}_{gm}^s = \breve{p}_{gm}^s + \tau_1$, where τ_1 is the optimal per unit tax. Thus, net returns for the legal GM variety become

(16) $$\underline{\Pi}_{gm}^h = p_{gm} - \underline{p}_{gm}^s + \phi A.$$

A diagrammatic analysis similar to Figure 2 would identify the three ranges of A values over which, increasing from zero, producers choose to infringe, choose the legal GM variety and choose the traditional variety. When a corrective tax is introduced to this environment, the total amount of the GM variety is reduced, but that portion of it which is legally produced falls and that portion of it which is produced illegally without purchased seed (or taxes) grows. As in case (b), government will choose the optimal rate of tax with full information about how the GM crop will be priced and (in this case) with knowledge about the extent to which infringement will incur. The resulting level of social welfare is

$$W_e = PS_e - D_e^{IE} - EC + F_e + TR_e = p_t - p_t^s + \frac{\gamma}{2} - (\alpha\delta_0 + \beta) + \frac{m^2}{4\delta_0\rho} + \frac{B^2}{\gamma - \phi + \delta_0\rho} \tag{17}$$
$$\frac{(c+m-B)^2}{6(\gamma-\phi)} - \frac{(4B+2c-m)^2}{12(2\gamma - 2\phi + 3\delta_0\rho)}.$$

Case (f): Infringement of IPRs, new corrective subsidy to address the externality

Government levies a subsidy η_1 per unit of traditional seed purchased, so that the price of traditional seed drops from p_t^s to $(p_t^s - \eta_1)$. Denoting the producer's net returns from the (subsidized) traditional crop as $\prod_t''$, gives

$$\prod_t'' = p_t - (p_t^s - \eta_1) + \gamma A. \tag{18}$$

As in case (c) there will be a decrease in the monopolist's optimal price to $p_{gm}''^{s}$, so that the producers' net returns from the production of the legal GM variety become

$$\prod_{gm}''^{h} = p_{gm} - p_{gm}''^{s} + \phi A. \tag{19}$$

One effect of the subsidy is to reduce total GM crop production and to increase the production of traditional crop output.

Social welfare (W_f) consists of producer surplus (PS_f), minus enforcement costs (EC), minus external effects (D_f^{IE}), minus subsidy payment (Pa_f) plus expected revenue earned through the penalty (F_f), which gives

$$W_f = PS_f - EC - D_f^{IE} - Pa_f + F_f = p_t - p_t^s + \frac{\gamma}{2} - (\alpha\delta_0 + \beta) + \frac{m^2}{4\delta_0\delta} \tag{20}$$
$$+ \frac{(B-c-m)^2}{6(\gamma-\phi)} - \frac{(2B-2c+m)(2B+2c-m)(4\gamma+3\delta_0\rho-4\phi)}{12[4(\gamma-\phi)^2 - 3\delta_0\rho(2\gamma+3\delta_0\rho-2\phi)]}.$$

The components of this expression are given in Table A1.

Comparison and summary of cases (a) through (f)

Cases (a) through (f) characterize all of the sub-game perfect, short run equilibrium outcomes attainable in the strategic game that was represented in Figure 1. In each case, the monopolist's optimal choice of price and quantity for the licensed GM seed variety, given any corrective tax or subsidy in place, allows a determination of the quantities of each crop variety that are grown by heterogeneous producers. Knowledge of the cost of the externality and of the government's enforcement activities allows a description of the level of social welfare that is achieved by domestic residents from activities in this sector of the agricultural economy.

Table A1 in the Appendix provide the analytical expressions for the principal components of domestic social welfare in each case. These tabulated results reflect the role of key assumptions requiring that no single crop variety is allowed to dominate the seed market for this crop, and that under imperfect enforcement, there is always some positive amount of infringement of IPRs.

The graphical analysis and the tabulated expressions show that a number of results established by Giannakas in a similar model also hold in this case. Specifically, (i) producers will produce the GM crop with illegally used seed when the price of GM seed is greater than the expected penalty from cheating; (ii) IPR infringement reduces the price of the new technology and the quantity supplied by the innovator; (iii) for a given tax regime, IPR infringement increases the adoption of the new technology by producers; (iv) imperfect IPR enforcement reduces the rents accruing to the innovator; and (v) IPR infringement increases the welfare of all domestic producers that use the GM variety.

Working from this common analytical base, the present paper adds the following results: The socially optimal corrective tax on legal GM seeds or corrective subsidy on traditional seeds reduces total production of the GM crop, with or without full enforcement. With perfect enforcement, the corrective tax and the corrective subsidy are equally effective policy instruments and both reach the same equilibrium level of social welfare. With imperfect enforcement, the optimal corrective tax (case (e)) increases the portion of the GM crop that is produced with illegal seed, relative to the no-tax case (d). Provided that the monopolist faces a linear demand curve and constant short run marginal costs, the static incidence of the optimal corrective tax is shared equally (on a per unit basis) by the foreign monopolist and the domestic seed purchasers. [The creation of the corrective tax may cause the foreign monopolist to lose more surplus than is indicated by tax payments alone, since the monopolist's quantity supplied also falls.] For a given tax or subsidy regime, the negative externalities that accompany the use of the GM seed variety are higher in magnitude under imperfect enforcement of the IPRs than under perfect enforcement of IPRs. [This follows directly from Giannakas's result (iii) in previous paragraph].

Numerical Illustration

In order to illustrate the analytical results obtained above, Table 1 uses a set of hypothetical parameter values that describe the exogenous features of producers' and monopolist's costs and returns in this economy. From these parameter values, and from the analytical expressions tabulated in the Appendix, one can evaluate numerically the expressions for social welfare and each of its components.

Giannakas previously showed that, in this type of economy, imperfect enforcement of IPRs raises domestic welfare, in part because it increases domestic use of a beneficial GM variety, and in part because it appropriates for domestic benefit some monopoly rents that would have been expatriated. What this paper shows is that where there is a negative externality (with a constant marginal damage function) those general results still hold. Moreover, the introduction of an optimal corrective tax or subsidy to address the externality is capable of raising domestic welfare even further. One of the effects of the tax or the subsidy is to reduce the level of the activity that generates the negative externality. As well, the tax alone is relatively effective at appropriating for domestic use additional monopoly rents that would have been expatriated.

Table 1. Numerical Illustration of Cases (a) through (f)

	Case (a)	Case (b)	Case (c)	Case (d)	Case (e)	Case (f)
Price of GM seed faced by domestic producers[a] ($/ton)	2375	3240	1510	1649	2471	1321
Quantity of legal GM seed (tons)	0.69	0.37	0.37	0.65	0.18	0.46
Quantity of illegal GM seed (tons)	NA[b]	NA	NA	0.31	0.46	0.25
Tax or subsidy rate per unit ($/ton)	NA	1730	1730	NA	1645	995
Producers' surplus ($)	6901	6439	8169	7764	7423	8106
Externality ($)	-500	-269	-269	-693	-474	-515
Enforcement cost ($)	NA	NA	NA	-900	-900	-900
Expected penalty ($)	NA	NA	NA	261	587	167
Tax revenue or subsidy payment ($)	NA	647	-1083	NA	302	-283
Innovator's rent ($)	[1302]	[378]	[378]	[742]	[59]	[588]
Social welfare[c] ($)	6401	6817	6817	6432	6938	6575

[a] Numerical illustration is based on the following parameter values:
$p_t = \$7000/ton$, $p_t^s = \$5250/ton$, $p_{gm} = \$6000/ton$, $\gamma = \$9000/ton$, $\phi = \$6300/ton$, $m = \$500/ton$, $\delta = 1$ (under perfect enforcement), $\delta = \delta_0 = 0.4$ (under imperfect enforcement), $\rho = \$13000/ton$, $\alpha = \$500$, $\beta = \$700$, $c = \$720/ton$.

[b] NA: Not applicable

[c] Social welfare is the sum of all rows from producers' surplus down, except for innovator's rent

Whereas the tax and subsidy are equally effective ways to increase social welfare in the case of perfect enforcement, it is clear that their distributional effects within the domestic economy differ considerably. In the case of imperfect enforcement, taxes are a relatively more effective policy instrument to address the presence of the externality. The optimal tax rate is relatively large and has a significant effect on social welfare, whereas the optimal rate of subsidy is relatively low, and the subsidy has an insignificant effect on social welfare.

Conclusion

Previous analysis of public policy toward biotechnology has focused on important questions such as whether to grant and whether to enforce intellectual property rights on GM varieties. Separate analysis has looked at the type and degree of harm that might accompany such technologies, such as when the GM variety generates a negative externality. The present paper integrates aspects of both issues, and does so in an analytical framework complete with the exercise of (foreign) market power and with heterogeneous (domestic) producers with diverse valuations of the new technology. The results of this analysis support the implementation of public policy in a strategic manner that must incorporate the optimizing behavior of all other agents. Whereas the use of a corrective tax provides a relatively more effective instrument than a corrective subsidy, there may be considerable scope to consider other incentives and instruments singly or jointly with those employed here.

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Table A1. Agents' Payoffs and Short-run Equilibria in Cases (a) through (f)

Components	(a): No infringement of IPRs, no corrective tax to address the externality	(b): No infringement of IPRs, new corrective tax to address the externality	(c): No Infringement of IPRs, new corrective subsidy to address the externality
Price of GM seed[a]	$p_{gm}^{s} = \dfrac{p_{gm} - p_t + p_t^s + m}{2}$	$\hat{p}_{gm}^{s} = \dfrac{B + m - \tau_0}{2}$	$\overset{=}{p}_{gm}^{s} = \dfrac{p_{gm} - p_t + p_t^s - \eta_0 + m}{2}$
Quantity of legal GM seed	$x_{gm}^{s} = \dfrac{p_{gm} - p_t + p_t^s - m}{2(\gamma - \phi)}$	$\widetilde{x}_{gm}^{s} = \dfrac{B - m - \tau_0}{2(\gamma - \phi)}$	$\overset{=}{x}_{gm}^{s} = \dfrac{\delta_0 \rho (B - m) - (\gamma - \phi) m}{2\delta_0 \rho (\gamma - \phi)}$
Quantity of illegal GM seed	NA	NA	NA
Optimal rate of tax or subsidy	NA	$\tau_0^* = \dfrac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$	$\eta_0^* = \dfrac{1}{3}(p_{gm} - p_t + p_t^s + 2c - m)$
Producers' surplus	$PS_a = p_t - p_t^s + \dfrac{\gamma}{2} + \dfrac{(B-m)^2}{8(\gamma - \phi)}$	$PS_b = p_t - p_t^s + \dfrac{\gamma}{2} + \dfrac{(B - m - \tau_0)^2}{8(\gamma - \phi)}$	$PS_c = p_t - p_t^s + \dfrac{\gamma}{2} + \eta_0 + \dfrac{(B - m - \eta_0)^2}{8(\gamma - \phi)}$
Externality	$D_a^{PE} = c \times x_{gm}^{s}$	$D_b^{PE} = c \times \widetilde{x}_{gm}^{s}$	$D_c^{PE} = c \times \overset{=}{x}_{gm}^{s}$
Expected Penalty[b]	NA	NA	NA
Tax revenue or subsidy payment	NA[c]	$TR_b = \tau_0 \times \widetilde{x}_{gm}^{s}$	$Pa_c = \eta_0 (1 - \overset{=}{x}_{gm}^{s})$
Innovator's rent	$IR_a = (p_{gm}^{s} - m) \times x_{gm}^{s}$	$IR_b = (\hat{p}_{gm}^{s} - m) \times \hat{x}_{gm}^{s}$	$IR_c = (\overset{=}{p}_{gm}^{s} - m) \times \overset{=}{x}_{gm}^{s}$

[a] $B = p_{gm} - p_t + p_t^s$

[b] Enforcement cost in cases (d), (e) and (f) is $\alpha\delta_0 + \beta$

[c] NA: Not applicable

Components	(d): Infringement of IPRs, no corrective tax to address the externality	(e): Infringement of IPRs, new corrective tax to address the externality	(f): Infringement of IPRs, new corrective subsidy to address the externality
Price of GM seed	$\bar{p}^{s}_{gm} = \frac{\delta_0 \rho B}{2(\gamma - \phi + \delta_0 \rho)} + \frac{m}{2}$	$\breve{p}^{s}_{gm} = \frac{\delta_0 \rho (p_{gm} - p_t + p_t^s)}{2(\gamma - \phi + \delta_0 \rho)} - \frac{\tau_1 - m}{2}$	$p''^{s}_{gm} = \frac{(p_{gm} - p_t + p_t^s - \eta_1)\delta_0 \rho}{2(\gamma - \phi + \delta_0 \rho} + \frac{m}{2}$
Legal GM seed	$x^{s}_{gm} = \frac{\delta_0 \rho (B - m) - (\gamma - \phi) m}{2\delta_0 \rho (\gamma - \phi)}$	$\underline{x}^{s}_{gm} = \frac{\delta_0 \rho (p_{gm} - p_t + p_t^s - m - \tau_1) - (\tau_1 + m)(\gamma - \phi)}{2(\gamma - \phi)\delta_0 \rho}$	$x''^{h}_{gm} = \frac{(p_{gm} - p_t + p_t^s - \eta_1 - m)\delta_0 \rho - m(\gamma - \phi)}{2(\gamma - \phi)\delta_0 \rho}$
Illegal GM seed	$x^{c}_{gm} = \frac{\delta_0 \rho (B + m) + (\gamma - \phi) m}{2\delta_0 \rho (\gamma - \phi + \delta_0 \rho)}$	$\underline{x}^{c}_{gm} = \frac{\delta_0 \rho (p_{gm} - p_t + p_t^s) + (\tau_1 + m)(\gamma - \phi + \delta_0 \rho)}{2(\gamma - \phi + \delta_0 \rho)\delta_0 \rho}$	$x''^{c}_{gm} = \frac{(p_{gm} - p_t + p_t^s - \eta_1 + m)\delta_0 \rho + m(\gamma - \phi)}{2(\gamma - \phi + \delta_0 \rho)\delta_0 \rho}$
Optimal rate of tax or subsidy	NA	$\tau_1^{*} = \delta_0 \rho [\frac{4B + 2c - m}{2\gamma - 2\phi + 3\delta_0 \rho} - \frac{B}{\gamma - \phi + \delta_0 \rho}]$	$\eta_1^{*} = B + \frac{2c - m - 2B}{2}[1 - \frac{\delta_0^2 \rho^2}{4\gamma^2 + 6\gamma\delta_0 \rho + 3\delta_0^2 \rho^2 - 8\gamma\phi - 6\phi\delta_0 \rho + 4\phi^2}]$
Producers' surplus	$PS_d = p_t - p_t^s + \frac{\gamma}{2} + \frac{m^2}{8\delta_0 \rho} + \frac{3B^2}{8(\gamma - \phi + \delta_0 \rho)} + \frac{(B - m)^2}{8(\gamma - \phi)}$	$PS_e = p_t - p_t^s + \frac{\gamma}{2} + \frac{(m + \tau_1)^2}{8\delta_0 \rho} + \frac{3B^2}{8(\gamma - \phi + \delta_0 \rho)} + \frac{(B - m - \tau_1)^2}{8(\gamma - \phi)}$	$PS_f = p_t - p_t^s + \frac{\gamma}{2} + \eta_1 + \frac{(-B + m + \eta_1)^2}{8(\gamma - \phi)} + \frac{m^2}{8\delta_0 \rho} + \frac{3(B - \eta_1)^2}{8(\gamma - \phi + \delta_0 \rho)}$
Externality	$D_d^{IE} = c \times x^{s}_{gm}$	$D_e^{IE} = c \times (\underline{x}^{h}_{gm} + \underline{x}^{c}_{gm})$	$D_f^{IE} = c \times (x''^{h}_{gm} + x''^{c}_{gm})$
Expected penalty[b]	$F_d = \rho \int_0^{A^c_{gm}} (\delta_0 A) dA$	$F_e = \rho \int_0^{A^{c(new)}_{gm}} (\delta_0 A) dA$	$F_f = \rho \int_0^{A''^{c}_{gm}} (\delta_0 A) dA$
Tax revenue or subsidy payment	NA	$TR_e = \tau_1 \times \underline{x}^{s}_{gm}$	$Pa_f = \eta_1 [1 - (x''^{h}_{gm} + x''^{c}_{gm})]$
Innovator's rent	$IR_d = (\bar{p}^{s}_{gm} - m) \times (x^{s}_{gm})$	$IR_e = (\breve{p}^{s}_{gm} - m) \times (\underline{x}^{s}_{gm})$	$IR_f = (p''^{s}_{gm} - m) \times x''^{s}_{gm}$

Footnotes

[1] Whereas Giannakas explores the implications of an *endogenous* enforcement policy under that the assumption that biotechnology conveys no externalities, the current article introduces such externalities and treats the enforcement regimes as *exogenous*, so as to focus on the effects of a corrective tax or subsidy as a policy instrument.

[2] Giannakas invokes the further assumption that there is a one-to-one correspondence between the levels of seed use and the supply of crop output for all producers. That assumption is relaxed here, so that the GM variety might result in yield or productivity differences that vary across producers.

[3] Figures (2) and (3) and this solution of the monopolist's problem are due to Giannakas. The analysis and results of cases (a) and (d) are analogous to those in Giannakas except for noted differences such as the introduction here of externalities that will lower social welfare. All other cases find no counterpart in Giannakas, since they introduce a corrective tax or subsidy to address the new externality and since (in (d), (e) and (f)) the level of enforcement is exogenous.

[4] In this example, the external effect is a social cost, and the term D_a^{PE} detracts from social welfare, W_a. In an example where the GM variety brought a productivity gain to some producers and a *positive* external benefit to other residents, the value of that benefit would be $-D_a^{PE}$. In such a case, any corrective tax on GM seed would become a corrective subsidy, and any corrective subsidy on the traditional seed would become a corrective tax.

[5] A subsidy might alternatively be offered in the market for GM seed, such as by providing a per unit subsidy to producers for each unit *reduction* in use of GM seed as measured from some historical benchmark, if one exists. The effects of a subsidy in that market are expected to parallel quite closely the effects of the corrective tax in case (b), and are not modeled formally here.