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On the Distribution and Adoption of Genetically Modified Seeds in Developing Countries

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Discussion papers in this series are intended to stimulate discussion among researchers, practitioners and policy makers. The papers mostly reflect work in progress. They have been reviewed internally by at least two colleagues of the institute.

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Table of Contents

Abstract

Given the proprietary nature of most genetically modified (GM) seed technologies, the question arises as to how farmers in developing countries can gain proper access to these innovations. Based on empirical observations, a theoretical model is developed which focuses on farmers' adoption decisions in response to the pricing strategies of a foreign patent holder and the government. If the government is able to commit to the announced policy, *subsidizing* the use of traditional seeds can increase coverage of GM technology and domestic welfare. The possibility of the government obtaining a license to distribute GM seeds domestically through a transfer to the monopolist is also considered.

Keywords: GM Seeds, Price Discrimination, Time Inconsistency, Transfers.

On the Distribution and Adoption of Genetically Modified Seeds in Developing Countries

Arnab K. Basu* and Matin Qaim†

1 Introduction

Most developing countries traditionally rely on public sector research for agricultural innovation. Internationally, however, the private sector is gaining in importance. New biotechnological breakthroughs and strengthened intellectual property rights (IPRs) have increased the incentives for corporate investments, while public support for agriculture has been declining (Pray and Umali-Deininger, 1998). Especially research and development (R & D) in the area of genetically modified (GM) crops are largely dominated by a few multinational companies. There is concern that biotechnology will bypass the developing world or, worse, that poor farmers might be exploited by foreign monopolist seed suppliers. Hence, the question as to how developing countries can ensure proper access to proprietary innovations is of central policy relevance (Evenson, 2004; Byerlee and Fischer, 2002; FAO, 2004).

Recent empirical studies demonstrate that GM crops can be beneficial for farmers in developing countries. Pray et al. (2002) show for cotton in China, and Qaim and Traxler (in press) for soybeans in Argentina, that these technologies can bring about major cost savings in pest control and reduce negative environmental externalities through reductions in the use of toxic pesticides. Studies by Qaim and Zilberman (2003) and Thirtle et al. (2003) reveal that GM crops can also increase yields in situations where pesticides are underused. For most of these early GM applications in developing countries, farmers' technology access was not a problem, because IPRs were not existent or not effectively enforced. Thus, monopoly power by foreign innovators was limited, and GM seed prices remained affordable. Corporate profit potentials are small, however, and it is unlikely that companies will commercialize their seed technologies on a larger scale under such conditions. Private incentive structures in developing countries will have to be improved

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through a higher level of IPR protection or other mechanisms to ensure a sustained inflow of proprietary innovations.[1] Member countries of the World Trade Organization are required to strengthen their IPRs under the Trade Related Intellectual Property Rights (TRIPs) agreement.

With stronger IPRs, prices of GM seeds will rise, thus deterring certain farmers from using them. Qaim and de Janvry (2003) showed for Bt (*Bacillus thuringiensis*) cotton in Argentina that the high monopoly seed price is a major barrier to adoption, especially for smallholder farmers. In such situations, the developing country government might want to intervene, in order to increase technology coverage and domestic welfare. This paper examines the optimal form of intervention in seed markets of developing economies. A theoretical model is developed, focusing on the adoption decision by agricultural producers in response to the pricing strategies by the patent holder of the GM seed technology and the government of the adopting country. We show that, in a scenario where IPR infringement is a non-issue and where GM seeds are priced higher than the traditional counterpart, the optimal form of intervention is to subsidize the price of traditional seeds. This counter-intuitive result follows from recognizing the fact that GM and traditional seeds are (imperfect) substitutes as inputs in production. Subsequently, lowering the price of traditional seeds forces the monopolist GM seed supplier to reduce the price of GM seeds in order to preserve market share.

The existing theoretical literature on pricing decisions of the GM patent holder and the subsequent adoption decisions by farmers has focused on two issues: (i) the incentives for R & D to develop GM seeds (Weaver and Kim, 2002) and (ii) the effect of IPR enforcement on pricing and adoption decisions (Giannakas, 2002; Chattopadhyay and Horbulyk, 2003). Weaver and Kim identify a key element in the pricing decision for GM seeds by a foreign monopolist: the patent holder of the GM technology is a *restrictive* monopolist in the sense that the range of its pricing power is contingent on the incentives for other technologies (e.g., traditional seeds and chemical regimes). Given this limited monopoly power, and under imperfect information regarding production conditions on the part of the patent holder, Weaver and Kim show that uniform pricing of GM seeds results in the appropriation of large parts of the benefits by the adopters.

[1] Also, public R & D investments will have to be expanded to address private research gaps. But the focus of this paper is on proprietary GM technologies.

In terms of IPRs, Giannakas postulates that complete deterrence of IPR infringement may not be optimal from the standpoint of the adopting country's welfare. Given that the patent holder is a restrictive monopolist, lax IPR enforcement pushes the monopolist to reduce the price of GM seeds in order to ensure positive rents. The lower price of GM seeds, in turn, enhances domestic welfare. Chattopadhyay and Horbulyk extend Giannakas' argument by incorporating explicitly the notion that GM technology confers a negative externality on the adopting country. Given this negative externality Chattopadhyay and Horbulyk show that a corrective tax on the price of GM seeds or a subsidy to the use of traditional seeds is consistent with welfare maximization of the adopting country. Either of these two policies reduce coverage of GM seeds in their model. However, worrying negative externalities, be it adverse impacts on the environment or consumer health, have not been shown in risk analyses related to the GM technologies commercialized up till now. On the contrary, hitherto applications of GM technologies in the small farm sector of developing countries resulted in substantial economic, social, and environmental benefits. Our purpose is to build a model that incorporates realistic features of GM seed adoption in developing countries, in order to extrapolate policy recommendations that favor increased coverage of GM seeds and enhanced domestic welfare.

As a starting point, we ignore the possibility of IPR infringement and any externalities subsequent upon the decision to adopt GM seeds. We follow Weaver and Kim in the sense that the supplier of GM seeds acts as a restrictive monopolist due to the existence of a competing traditional seed market which imposes an upper bound on the price that the monopolist can charge. This latter observation provides the key in analyzing how policy-makers in developing countries can best intervene in the agricultural sector to ensure that welfare of the economy is maximized. We consider a small open economy in the absence of labeling (thus ruling out the possibility of an output-price differential) where the government intervenes by maximizing the sum of producers' surplus and net revenue from the sale of traditional seeds to determine the optimal form of intervention. Subsequent upon the form of intervention we focus on the coverage of GM seeds within the economy. In doing so, we account for two crucial elements. First, whether or not the monopolist GM seed supplier has perfect information regarding the production conditions within the economy. If the monopolist has imperfect information then GM seeds are priced uniformly, while perfect information allows the monopolist to pursue first-degree price discrimination. Second, whether or not the government is credible and can therefore commit to its announced form of intervention. This is particularly important since the monopolist rationally accounts for the possibility that the announced policy may be time-inconsistent in its pricing decision for GM seeds.

The basic framework explores a sequential game *à la* Giannakas, between the foreign monopolist supplier and the government to determine the prices of GM and traditional seeds. Depending on whether the monopolist has perfect or imperfect information, the domestic government as the first mover announces the optimal form of intervention in the traditional seed market by maximizing producers' surplus. Subsequently, the monopolist, by accounting for the possibility that the government's announced policy might be time-inconsistent, sets the price of GM seeds. Lastly, the heterogeneous producers self-select into the usage of either GM or traditional seeds. In both the perfect and imperfect information scenarios, we find that, if the domestic government can credibly commit to the announced policy, the optimal form of intervention entails *subsidizing* the use of traditional seeds. Our findings are in contrast to observed practices in developing countries like Mexico that are known to subsidize the price of GM seeds (cf. Traxler et al., 2001).

Finally, we consider the possibility of the government obtaining the ownership right to distribute GM seeds domestically through a lump-sum royalty, that is, a transfer to the patent holder. The foreign company would only agree to such an arrangement, if the transfer compensates for the foregone monopoly rent, while for the government the prerequisite would be that domestic welfare be increased. We show that, under uniform pricing of GM seeds, there exists a positive transfer from the government to the monopolist that leads to a higher level of domestic welfare by allowing the government to practice marginal cost pricing for both GM and traditional seeds. However, when the monopolist can practice perfect discrimination, the possibility of a strictly welfare improving transfer does not exist.

The plan of the paper is as follows: in the next section we use the empirical example of Bt cotton in Argentina to show that there is indeed a positive correlation between traditional seed prices and farmers' willingness to pay (WTP) for GM seeds. This association supports the assumption of a restrictive monopoly, which is key for the analytical results. In the following sections, the basic theoretical model is developed, and the pricing strategies of GM and traditional seeds are explored under the perfect and imperfect information scenarios. Then, the issue of transfers is analyzed, and the last section concludes.

2 Empirical Evidence

Insect-resistant Bt cotton has been commercialized in a number of countries, and, due to weak IPR protection, adoption has mostly been very fast and widespread. However, in Argentina Bt cotton technology is patented, and GM seeds are marketed by a monopolist supplier. Motivated by the relatively low adoption rates in Argentina, Qaim and de Janvry (2003) analyzed the farmers' WTP for Bt cotton seeds and the expected level of demand under different pricing regimes. They used a double-bounded contingent valuation approach and survey data collected in Argentina in 2001. For econometric estimation, the following log-likelihood function was employed:

$$lnL = \sum_{i=1}^{n} I^U ln[1-\phi(\frac{P^U-\beta'\nu}{\sigma})]+I^{UL}ln[\phi(\frac{P^U-\beta'\nu}{\sigma})-\phi(\frac{P^L-\beta'\nu}{\sigma})]+I^L ln[\phi(\frac{P^L-\beta'\nu}{\sigma})]$$

where P^U is the upper-bound and P^L the lower-bound price bid from the contingent valuation survey. I^U, I^{UL}, and I^L are indicator variables for respondents with a WTP above P^U, between P^U and P^L, and below P^L, respectively. ν is a vector of farm-specific variables influencing the WTP, and β' is the vector of coefficients to be estimated. These coefficients can directly be interpreted as marginal effects.

Qaim and de Janvry showed a significant influence of various demographic, agro-ecological and institutional characteristics on the WTP for Bt cotton, but they did not include the price of traditional seeds as an explanatory variable. We use the same model and data for testing our hypothesis that the price for traditional seeds is positively correlated with the WTP for GM seeds. Since Argentine cotton farmers obtain their traditional seeds from a variety of formal and informal sources, there is sufficient price variation in the sample for robust estimates. The summary statistics of the explanatory variables and the estimation results are shown in Table 1.

Unsurprisingly, larger and better educated farmers have a higher WTP for Bt cotton, whereas a credit constraint has a negative effect. The coefficient for the traditional seed price is positive and significant.[2] Every additional dollar that a farmer spends on buying traditional cotton seeds increases his WTP for Bt seeds by almost 1.5 dollars. This suggests that a subsidy in the traditional seed market should indeed induce the profit-maximizing GM seed supplier to reduce its monopoly price, thus corroborating the theoretical findings presented in later sections. Producers who face higher expenditures for chemical insecticides also have a higher WTP for Bt technology. Since there is usually a positive correlation between insect infestation and the extent of insecticide use, the variable insecticide expenditure can be seen as a proxy for pest pressure. Pest pressure varies between farmers according to agroecological conditions at the micro level. The higher the pest pressure, the more beneficial Bt technology will be for a farmer, a result which is used to model GM technology in our theoretical framework.

3 Basic Model

The model we consider has three groups or agents: (i) the monopolist GM seed supplier; (ii) producers who self-select into either of two groups — user of GM seeds or traditional ones and (iii) the government of the developing economy which undertakes the twin role of procuring traditional seeds from perfectly competitive traditional seed suppliers and selling them to the adopters of traditional seeds as well as maximizing the welfare of its constituents via the choice of the optimal form of intervention in the seed market. In essence we have in mind an economy where traditional better quality seeds are sold to adopters through an agency like the seed marketing board.

The economy we consider has N total producers. There are two types of technologies available to an individual producer in the economy: traditional and GM seeds. GM seeds are sold by a foreign monopolist, and either guarantee the same level of output with a relatively lower use of pesticide (and hence lower input costs) or a higher level of output with the same intensity of pesticide usage, as compared to traditional seeds.

The technological specification for crops produced via traditional seed use is given by

$$Q_t = F(y) + G(x) - D^i \tag{1}$$

[2]Since farmers choose their seed source, the traditional seed price might be associated with an endogeneity problem. However, leaving the variable out only has minor effects on the other estimates, and the coefficients are very similar to those in Qaim and de Janvry (2003). We therefore conclude that the seed price variable does not cause a systematic bias.

where Q_t is the output from using traditional seeds; y is the level of a composite non-pesticide input while x is the level of pesticide input. The functions $F()$ and $G()$ are concave and twice differentiable. The parameter D^i is producer specific and captures the extent of pest pressure on the land. D follows a uniform distribution over the interval $[0, 1]$ with an associated density function $\sigma(D) > 0$ and a cumulative distribution function $\Sigma(D)$. Thus, higher values of D capture increasing pest pressure.[3]

On the other hand, the technology available for production via GM seeds is given by

$$Q_g = F(y) + G(x + \delta) - \alpha D^i \tag{2}$$

where Q_g is the output from using GM seeds while y and x are, once again, the composite non-pesticide and pesticide inputs respectively. $\delta > 0$ is a shift parameter that captures the fact that the use of GM yields a higher level of output with the same level of pesticide use. Finally, $0 < \alpha < 1$ signifies that the damage to crops under GM seed usage is lower as compared to the use of traditional ones. In other words, α is negatively correlated with the GM technology's effectiveness to control pest damage. Note also that α is identical across producers in the sense that all producers are able to reduce the damage to their crops by the same proportion via the use of GM seeds.

Although producers differ according to pest pressure on their lands, we assume that they are endowed with identical plot size T. Therefore, if s_g and s_t are the seed requirements per unit acre for GM and traditional crops respectively, then each producer requires Ts_g and Ts_t amount of seeds. For analytical simplicity, we normalize T to be unity. Further, in concert with empirical evidence indicating that the land-seed ratio is the same irrespective of whether GM or traditional seeds are planted, we henceforth set $s_g = s_t = s$. With the technological specifications in place, we start with the derivation of the input demand functions for pesticides and the composite input for the two types of seed users.

Ruling out the scenario in which there is partial adoption on a producer's plot, we denote π_t as the profit of a traditional seed user. Therefore,

$$\pi_t = PQ_t - p_t s - p_x x - p_y y = P[F(y) + G(x) - D^i] - p_t s - p_x x - p_y y$$

[3]GM crops available up till now facilitate pest management in farmers' fields. For non-pest-related GM technologies, which might be commercialized in the future, D can also represent any other characteristic causing heterogeneity among farmers (e. g., land quality).

where P is the price per unit output of the traditional crop; p_t is the price per unit of traditional seeds while p_x and p_y are per-unit prices of the pesticide and the composite non-pesticide input respectively. Maximizing π_t with respect to x and y yields,

$$\begin{aligned}\frac{\partial \pi_t}{\partial y} &= PF'(y) - p_y = 0 \Rightarrow y^* = f(\frac{p_y}{P}) \\ \frac{\partial \pi_t}{\partial x} &= PG'(x) - p_x = 0 \Rightarrow x^* = g(\frac{p_x}{P})\end{aligned}$$

Substituting for y^* and x^* into the profit function yields

$$\begin{aligned}\pi_t &= P[F(y^*) + G(x^*) - D^i] - p_t s - p_x x^* - p_y y^* \\ &= P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P})) - D^i] - p_t s - p_x g(\frac{p_x}{P}) - p_y f(\frac{p_y}{P})\end{aligned} \quad (3)$$

Similarly, profit of a producer who opts for GM seeds is given by π_g, where

$$\pi_g = PQ_g - p_g s - p_x x - p_y y = P(F(y) + G(x+\delta) - \alpha D^i) - p_g s - p_x x - p_y y$$

P is the price of the output produced via GM. We assume that the output price of GM and traditional crops are identical as there exists no clear evidence on any price differential between the two. Maximizing profit of a GM seed user we have

$$\begin{aligned}\frac{\partial \pi_g}{\partial y} &= PF'(y) - p_y = 0 \Rightarrow y^* = f(\frac{p_y}{P}) \\ \frac{\partial \pi_g}{\partial x} &= PG'(x+\delta) - p_x = 0 \Rightarrow x^* = g(\frac{p_x}{P}) - \delta\end{aligned}$$

Substituting for y^* and x^* into the profit function yields

$$\begin{aligned}\pi_g &= P[F(y^*) + G(x^*+\delta) - \alpha D^i] - p_g s - p_x x^* - p_y y^* \\ &= P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P}) - \delta + \delta) - \alpha D^i] - p_g s - p_x[g(\frac{p_x}{P}) - \delta] - p_y f(\frac{p_y}{P})\end{aligned} \quad (4)$$

From the above set-up it is easy to see that a producer endowed with land quality $D \in [0,1]$ will choose to use GM seeds if and only if $\pi_g \geq \pi_t$, or

$$\begin{aligned}& P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P}) - \delta + \delta) - \alpha D^i] - p_g s - p_x[g(\frac{p_x}{P}) - \delta] - p_y f(\frac{p_y}{P}) \\ \geq\ & P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P})) - D^i] - p_t s - p_x g(\frac{p_x}{P}) - p_y f(\frac{p_y}{P})\end{aligned}$$

Normalizing the output price of traditional and GM crops to unity (i.e., $P = 1$) and rearranging the above equation, we identify the marginal producer who is willing to adopt GM seed as:

$$\bar{D} \geq \frac{(p_g - p_t)s - p_x \delta}{(1-\alpha)} \quad (5)$$

Therefore, equation (5) provides a cut-off point on the distribution of pest pressure on land such that all producers with pest pressure *greater* than or equal to the critical level, $\bar{D}$, will self-select into the group that chooses to use GM seeds. In other words, the higher is the pest pressure (and hence the greater the damage under traditional seed use), the more likely it is that a producer will opt for GM seeds. Thus, the number of producers who opt for traditional seeds is $N\Sigma(\bar{D})$ while the number of producers who opt for GM seeds is $N[1 - \Sigma(\bar{D})]$.

Equation (5) above also allows us to check for the response of the marginal producer (and hence the total number of producers who opt for GM seeds) to changes in the various parameters. For instance, and as should be expected, an increase in the price of GM seeds (p_g) decreases the number of producers who opt for GM while an increase in the price of traditional seeds (p_t) shifts the number of producers in favor of GM. Second, an increase in the price of the pesticide input (p_x) increases the number of producers who adopt GM seeds, as the latter requires a lower use of pesticides to generate the same output. Third, the intensity of seed requirement per unit of land plays a role in the number of producer who self-select into the use of GM in the sense that the higher the seed requirement the lower is the number of producers who use GM, as long as GM seeds are costlier than their traditional counterparts. Finally, and obviously, the lower the damage from planting GM seeds (lower the value of α) the larger is the number of producers willing to adopt GM seeds.

Simple manipulation of equation (5) also allows us to identify an individual producers' WTP for GM seeds, p_g^i. Specifically,

$$p_g^i = \frac{(1-\alpha)D^i}{s} + \frac{p_x\delta}{s} + p_t \tag{6}$$

From equation (6) above, the WTP for GM seeds is is positively related to the pest pressure on land. Additionally, the WTP rises with an increase in either (i) the price of traditional seeds, p_t, (ii) the price of the pesticide input, p_x and (iii) the degree by which GM seeds reduce damage to crops (smaller α). These theoretical findings are consistent with the empirical evidence reported in the previous section. On the other hand, WTP for GM seeds falls with an increase in the seed requirement, as profits decline relatively more in comparison with the profits under traditional seed use given that the price of GM seeds is greater than the traditional ones. Figure I plots producers' WTP as a function of pest pressure on land. All else constant, the higher the pest pressure the higher is the WTP for GM seeds.

4 Monopolist Supplier of GM Seeds and Optimal Intervention in the Traditional Seed Market

GM seeds are supplied by a foreign monopolist who can either price GM seeds uniformly (under imperfect information) or act as a perfectly discriminating monopolist (under perfect information). In this setting, the government of the developing country wants to intervene in order to prevent excessive pricing, increase GM adoption, and maximize domestic welfare. As was mentioned already, and as will be shown analytically below, this can be achieved through a subsidy in the traditional seed market.[4] We assume the logical sequence that the government is the first mover in announcing whether it chooses to intervene in the traditional seed market. After the government's announcement, the monopolist supplier announces the price of GM seeds (p_g). Given these two prices domestic producers self-select into the usage of GM and traditional seeds. However, if the government is not credible then it cannot commit to the announced form of intervention and consequently reneges after the monopolist announces the price of GM seeds. Under rational expectation on the part of the monopolist, the problem of time-inconsistency is incorporated *ex-ante* in the profit maximizing calculus and hence in the pricing of GM seeds. Thus, for both the pricing scenarios for the monopolist (uniform and discriminatory), we consider the first and second-best regimes (respectively, when the government credibly commits to the announced form of intervention and when the government reneges), in the determination of the adoption decision by domestic producers and consequently coverage of GM seeds. We start with the case of asymmetric information on the part of the monopolist, or uniform pricing.

Uniform Pricing of GM Seeds

[4] In some cases, a formal market for traditional seeds might not exist, because farmers exclusively use farm-saved seeds or informal sources, so that a seed subsidy would not be practicable. Yet, such locations are hardly targeted by foreign GM seed companies anyway. For a subsidy to work it is not necessary that farmers buy seeds in formal markets every single growing season. Even if they buy fresh seeds only occasionally, a government intervention in the traditional market would influence their WTP for GM seeds and thus the pricing strategy of the monopolist.

In the event where the monopolist has imperfect information regarding the distribution of D, the per-unit price of GM seeds is invariant to pest pressure.

Let p_t^e denote the price of traditional seeds that the foreign monopolist *and* the producers expect the government of the developing economy to charge. In this case, the cut-off on the distribution of pest pressure (from equation (5)) that determines the self-selection of producers between GM and traditional seed use is given by

$$\bar{D}_u \equiv \frac{(p_g - p_t^e)s}{(1-\alpha)} - \frac{p_x \delta}{(1-\alpha)} \tag{7}$$

Given the demand for GM seeds $N \int_{\bar{D}_u}^{D^+} s d\Sigma(D) = N \int_{\bar{D}_u}^{D^+} \frac{s}{D^+} dD$, and the marginal cost of producing GM seeds as w, a uniform pricing monopolist's profit is given by

$$\Pi_u(p_g,\ p_t^e) = N \int_{\bar{D}_u}^{D^+} \frac{(p_g - w)s}{D^+} dD$$

As shown in Appendix I, by substituting for $\bar{D}_u$ from equation (7) into the first order condition of profit maximization with respect to p_g, the best-response function of the monopolist can be derived as

$$p_g(p_t^e) = \frac{1}{2}\left(\frac{(1-\alpha)D^+}{s} + (p_t^e + w) + \frac{p_x\delta}{s}\right) \tag{8}$$

Figure II plots the best response function of the foreign monopolist engaged in uniform pricing. The line MM represents the function $p_g(p_t^e)$ with intercept $\frac{1}{2}\left(\frac{(1-\alpha)D^+}{s} + w + \frac{p_x\delta}{s}\right)$ and slope $\frac{1}{2}$.

The iso-profit contours of the monopolist can, in turn, be derived from

$$d\Pi_u = \frac{N}{D^+} s \left(D^+ - [\frac{(p_g - p_t^e)s - p_x\delta}{(1-\alpha)}] - \frac{(p_g - w)s}{(1-\alpha)}\right) dp_g + \frac{N}{D^+} s \frac{(p_g - w)s}{(1-\alpha)} dp_t^e = 0$$

which implies that

$$\frac{dp_t^e}{dp_g} = -\frac{\frac{(1-\alpha)}{s}D^+ + \frac{p_x\delta}{s} + p_t^e + w - 2p_g}{(p_g - w)}$$

and

$$\frac{d^2 p_t^e}{d(p_g)^2} = \frac{\frac{(1-\alpha)}{s}[D^+ - \bar{D}_u]}{(p_g - w)^2} > 0$$

Thus, the iso-profit contours of the monopolist, UU in Figure II, are convex to the origin and since

$$\frac{d\Pi_u}{dp_t^e} = \frac{N}{D^+}\frac{s^2}{(1-\alpha)}(p_g - w) > 0,$$

higher iso-profit curves imply higher profits for the monopolist.

First-Best Regime: We start with the first-best regime where the domestic government has credibility and hence sets, via intervention, the price of traditional seeds as $p_t = p_t^e$. Thus, substituting for p_g from equation (8) into equation (7) and equating $p_t = p_t^e$, we have

$$\bar{D}_u \equiv \frac{1}{2}\left(D^+ - \frac{(p_t - w)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}\right) \tag{9}$$

Noting from the above equation that $\frac{d\bar{D}_u}{dp_t} = \frac{1}{2}\frac{s}{(1-\alpha)}$ and taking into account the positive relationship between the price of GM seeds and the price of traditional seeds ($\frac{dp_g}{dp_t} = \frac{1}{2}$), the domestic government maximizes the sum of total producers' surplus and the net revenue from the sale of traditional seeds under uniform pricing by the monopolist (V_u) in order to determine the optimal price of traditional seeds. Or,

$$\max_{p_t} \;\; V_u = N\int_{\bar{D}_u}^{D^+} \pi_g d\Sigma(D) + N\int_0^{\bar{D}_u} \pi_t d\Sigma(D) + N\int_0^{\bar{D}_u}(p_t - z)sd\Sigma(D)$$

where $N\int_{\bar{D}_u}^{D^+} \pi_g d\Sigma(D)$ is the total surplus of producers using GM seeds; $N\int_0^{\bar{D}_u} \pi_t d\Sigma(D)$ is the total surplus of producers using traditional seeds and $N\int_0^{\bar{D}_u}(p_t - z)sd\Sigma(D)$ is the net revenue of the government from selling traditional seeds. z is the marginal cost of producing traditional seeds, and with perfectly competitive traditional seed suppliers, z is also the procurement cost incurred by the government. The marginal costs of traditional and GM seed production depend on where and under what conditions seed production takes place. If produced under identical conditions, w might be equal to z. However, since the distribution of GM seeds is associated with additional marginal costs, such as extension and monitoring efforts, it is fair to assume that $w > z$ in most cases. Note that the net revenue of the government satisfies the budget constraint, $N\Sigma(D)[p_t - z]s + T = 0$, where T is the lump-sum non-distortionary tax imposed on the constituents if $p_t < z$ or a lump-sum subsidy that is redistributed if $p_t > z$.

Since

$$\begin{aligned}
\pi_t &= F(y^*) + G(x^*) - D^i - p_t s - p_x x^* - p_y y^* \\
\pi_g &= F(y^*) + G(x^*) - \alpha D^i - p_g s - p_x x^* - p_y y^* + p_x\delta
\end{aligned}$$

we denote $F(y^*) + G(x^*) - p_x x^* - p_y y^* = \Omega$. Thus, national welfare maximization for the developing economy entails,

$$\begin{aligned}\max_{p_t} \ V_u &= N \int_{\bar{D}_u}^{D^+} \left(\Omega - \alpha D^i - p_g s + p_x \delta\right) d\Sigma(D) + N \int_0^{\bar{D}_u} \left(\Omega - D^i - p_t s\right) d\Sigma(D) \\ &+ N \int_0^{\bar{D}_u} (p_t - z) s d\Sigma(D)\end{aligned}$$

As derived in detail in Appendix II, the first order condition associated with the above problem, evaluated for the marginal producer of GM ($\bar{D}_u$), is given by

$$\frac{(D^+ - \bar{D}_u)(1-\alpha)}{s} = z - p_t$$

Since the left hand side of the above equation is positive, the optimal pricing strategy for traditional seeds by the domestic government involves pricing traditional seeds below their associated marginal cost, or a subsidy to the per-unit price of traditional seeds.

By substituting for $\bar{D}_u$ from equation (9) we solve for the price of traditional seeds as

$$p_t = \frac{2}{3} z + \frac{1}{3} w - \frac{1}{3} \frac{D^+(1-\alpha)}{s} - \frac{1}{3} \frac{p_x \delta}{s} \tag{10}$$

and substituting this value of p_t into equation (8) (the best-response function of the monopolist) we solve for the price of GM seeds as

$$p_g = \frac{1}{3} \frac{D^+(1-\alpha)}{s} + \frac{2}{3} w + \frac{1}{3} z + \frac{1}{3} \frac{p_x \delta}{s} \tag{11}$$

Given the values of p_g and p_t, the number of producers who use GM seeds under the first-best regime (credible domestic government) is given as, $N[1 - \Sigma(\bar{D}_u^C)]$ with

$$\bar{D}_u^C = \frac{2}{3} D^+ + \frac{1}{3} \frac{(w-z)s}{(1-\alpha)} - \frac{1}{3} \frac{p_x \delta}{(1-\alpha)} \tag{12}$$

Finally the optimal per-unit price subsidy, ϕ_u^C, on traditional seeds is given by

$$\phi_u^C = (z - p_t) = \frac{1}{3} \left(\frac{D^+(1-\alpha)}{s} - (w - z) + \frac{p_x \delta}{s} \right) \tag{13}$$

The subsidy increases with an increase in either p_x or z and decreases with an increase in w. An increase in p_x has two effects that both benefit the monopolist supplier of GM seeds: (i) it increases the number of producers who opt for GM seed usage which, in turn, lowers the demand for traditional seeds and has an adverse impact on government revenue and (ii) increases the WTP of domestic producers for GM seeds, thus allowing the monopolist to extract a larger surplus. The government being the first-mover, pre-empts this possibility by skewing the incentives for domestic producers towards the use of traditional seeds via a subsidy. An increase in the marginal cost of producing traditional seeds has the effect of raising the price of traditional seeds thereby increasing demand for GM seeds and allowing the monopolist to extract a larger surplus. Conversely, a higher marginal cost of producing GM seeds implies that the price per-unit of GM seed is higher for the marginal producer who finds it relatively beneficial to use traditional seeds. Further, from equation (13), a large range of pest pressure, $(D^+ - 0)$, translates into both a higher number of producers opting for GM seed as well as a higher WTP for GM seeds, which again entails a higher level of subsidy to curb the monopolist's profit. On the other hand, a higher seed requirement lowers the WTP for GM seeds for all producers as input costs rise. In this case — a lower number of GM seed users and a lower WTP for GM seeds — require a lower level of subsidy.

We now turn to the derivation of the iso-welfare contours for the government. Note that

$$dV_u = -\frac{N}{D^+} s[D^+ - \bar{D}_u] dp_g - \frac{1}{2}\frac{N}{D^+} s\left([D^+ - \bar{D}_u] + (p_t - z)\frac{s}{(1-\alpha)}\right) dp_t = 0$$

Therefore,

$$\begin{aligned}\frac{dp_g}{dp_t} &= -\frac{1}{2}\frac{[D^+ - \bar{D}_u] + (p_t - z)\frac{s}{(1-\alpha)}}{[D^+ - \bar{D}_u]} \\ &= -\frac{1}{2}\left(1 + \frac{(p_t - z)}{[D^+ - \bar{D}_u]}\frac{s}{(1-\alpha)}\right)\end{aligned}$$

Thus,

$$\frac{dp_g}{dp_t}\begin{cases} > 0 & \text{if } \frac{(p_t - z)}{[D^+ - \bar{D}_u]}\frac{s}{(1-\alpha)} < -1 \\ = 0 & \text{if } \frac{(p_t - z)}{[D^+ - \bar{D}_u]}\frac{s}{(1-\alpha)} = -1 \\ < 0 & \text{if } p_t \geq z \end{cases}$$

In Figure II the curves VV plot the iso-welfare contours of the developing economy. Note from above that since $\frac{\partial V_u}{\partial p_t} < 0$ lower iso-welfare curves denote a *higher* level of welfare for the developing economy.[5] Under the first best regime, equilibrium is attained at point

[5]
$$\frac{dV_u}{dp_t} = -\frac{1}{2}\frac{N}{D^+} s\left([D^+ - \bar{D}_u] + (p_t - z)\frac{s}{(1-\alpha)}\right) < 0.$$

X where the monopolist's best-response function is tangent to the iso-welfare curve V^o, with $(z - p_t) = \phi_u^C$ as the per-unit level of subsidy to traditional seeds.[6]

Second-Best Regime: We now consider the optimal prices of GM and traditional seeds when the government's announcement of p_t lacks credibility. In other words, the government reneges on p_t *after* the monopolist has announced p_g. Let $\psi(p_t^e)$ be the price of traditional seeds announced by the government if the monopolist and domestic producers believe that p_t^e is the price that the government will eventually set. Given,

$$\bar{D}_u \equiv \frac{(p_g - p_t^e)s}{(1-\alpha)} - \frac{p_x \delta}{(1-\alpha)}$$

The government maximizes

$$\begin{aligned}
\max_{\psi(p_t^e)} \ V_u \ &= \ N \int_{\bar{D}_u}^{D^+} \left(\Omega - \alpha D^i - p_g(p_t^e)s + p_x\delta\right) d\Sigma(D) + N \int_0^{\bar{D}_u} \left(\Omega - D^i - \psi(p_t^e)s\right) d\Sigma(D) \\
&\quad + N \int_0^{\bar{D}_u} (\psi(p_t^e) - z) s d\Sigma(D)
\end{aligned}$$

under the assumption that $p_g(\psi(p_t^e))$ is constant. The first order condition associated with the above maximization problem yields,

$$\frac{\partial V_u}{\partial \psi(p_t^e)} \Big|_{p_g(\psi(p_t^e))=const} = -N \frac{(\psi(p_t^e) - z)}{D^+} s \frac{d\bar{D}_u}{d\psi(p_t^e)} = 0$$

or $\psi(p_t^e) = p_t = z$. Therefore, in the event that the government cannot commit to the announced price, traditional seeds are priced at their associated marginal cost. Given rational expectations on the part of the monopolist, the price of GM seeds for the producers is derived from the best-response function of the monopolist by substituting for $p_t^e = z$. Therefore,

$$p_g = \frac{1}{2}\left(\frac{(1-\alpha)D^+}{s} + (z + w) + \frac{p_x\delta}{s}\right) \tag{14}$$

Figure III depicts the equilibrium when the government cannot commit to the announced price of traditional seeds. In the bottom quadrant of the Figure, the 45^o line equates

[6] Point X captures the fact that the slope of the iso-welfare curve equals the slope of the monopolist's best-response function, i.e.,

$$\frac{dp_g}{dp_t} = -\frac{1}{2}\left(1 + \frac{(p_t - z)}{[D^+ - \bar{D}_u]} \frac{s}{(1-\alpha)}\right) = \frac{1}{2} = \frac{\partial p_g}{\partial p_t}$$

$p_t^e = p_t$ while the top quadrant captures the best-response function of the monopolist GM seed supplier, (line MM). Note that point A captures the fact that domestic welfare is maximized when traditional seeds are priced at marginal cost while point B determines the price of GM seeds when traditional seeds are priced at marginal cost.

Substituting for $p_t = z$ and for p_g from equation (14) into equation (7) determines the number of producers who self-select to use GM seeds as $N[1 - \Sigma(\bar{D}_u^{NC})]$ when the government cannot credibly commit to the announced price of traditional seeds, where

$$\bar{D}_u^{NC} = \frac{1}{2}\left(D^+ + \frac{(w-z)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}\right) \tag{15}$$

Finally, from a comparison of equations (12) and (15), note that coverage of GM seeds with a credible regime can still be higher than the coverage of a non-credible government. The intuition follows from the fact that even though a higher price of traditional seeds under a non-credible government leads more producers to opt for GM seeds — the best-response function of the monopolist, wherein the price of GM seeds depends positively on the price of traditional ones, dictates that the uniform price of GM seeds charged by the monopolist is also higher. This second effect may run contrary to the first and reduce the incentive for producers to opt for GM seeds under a non-credible government. Specifically, GM coverage of a credible government is greater when,

$$\bar{D}_u^C < \bar{D}_u^{NC} \Leftrightarrow \frac{1}{6}\frac{(w-z)s}{(1-\alpha)} - \frac{1}{6}\frac{p_x\delta}{(1-\alpha)} - \frac{1}{6}D^+ > 0$$

a sufficient condition for which is either (i) $(w-z)s$ is large or (ii) $p_x\delta$ and the range of pest pressure, $(D^+ - 0)$ are small.

Pricing of GM Seeds under Perfect Discrimination

In this sub-section we explore the situation where the monopolist has full information about the producers, thus implementing perfect price discrimination. We make this assumption for analytical purposes to demonstrate the extreme case. Due to prohibitive transaction costs, perfect discrimination is not viable in reality. Yet, some form of regional price discrimination has been practiced, e.g., for Bt cotton seeds in Mexico and South Africa (Traxler et al., 2001; Gouse et al., 2003). If the monopolist supplier of GM seeds has perfect information about the distribution of D then $p_g(D)$ varies positively with D. First, note that the marginal producer in this situation is determined by

$$\bar{D}_d = \frac{(p_g - p_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)} \equiv \frac{(w-p_t)s}{(1-\alpha)} + \frac{p_x\delta}{(1-\alpha)}$$

since the lowest price charged by the perfectly discriminating monopolist (the price per-unit of GM seeds charged to the marginal producer) equals the marginal cost of producing GM seeds, w.

Given the demand for GM seeds, $N\int_{\bar{D}_d}^{D^+} s d\Sigma(D) = N\int_{\bar{D}_d}^{D^+} \frac{s}{D^+} dD$, a perfectly discriminating monopolist's profit (Π_d) is

$$\Pi_d = N\int_{\bar{D}_d}^{D^+} \left(\frac{(p_g(D)-w)s}{D^+}\right) dD$$

where $\bar{D}_d$ denotes the pest pressure for the marginal producer who is just indifferent between the choice of GM and traditional seed use under perfect discrimination.

Once again, let p_t^e be the expected price of traditional seeds that the monopolist and the domestic producers expect the government to set. Given p_t^e, the monopolist sets

$$p_g(D, p_t^e) = \frac{D(1-\alpha)}{s} + \frac{p_x\delta}{s} + p_t^e \tag{16}$$

$\forall D \in [\bar{D}_d, D^+]$. With the above observations, we now turn to the issue of optimal intervention in the market for traditional seeds.

First-Best Regime: Suppose the government is credible and commits to the announced price of traditional seeds. Thus, $p_t = p_t^e$. Taking into account the positive relationship between p_g and p_t (from equation (16)), the domestic government maximizes the sum of total producer surplus (surplus of both GM and traditional seed users) and net revenue from the sale of traditional seeds, V_d, by the choice of p_t as:

$$\begin{aligned}\max_{p_t} \; V_d \;&=\; N\int_{\bar{D}_d}^{D^+} \left(\Omega - \alpha D^i - p_g(D,p_t)s + p_x\delta\right) d\Sigma(D) + N\int_0^{\bar{D}_d} \left(\Omega - D^i - p_t s\right) d\Sigma(D) \\ &\quad + N\int_0^{\bar{D}_d} (p_t - z) s d\Sigma(D)\end{aligned}$$

Where $N\int_{\bar{D}_d}^{D^+} (\Omega - \alpha D^i - p_g(D,p_t)s + p_x\delta)\, d\Sigma(D)$ is the total surplus of producers using GM seeds; $N\int_0^{\bar{D}_d} (\Omega - D^i - p_t s)\, d\Sigma(D)$ is the total surplus of producers using traditional seeds and $N\int_0^{\bar{D}_d}(p_t - z)sd\Sigma(D)$ is the net revenue from the sale of traditional seeds. Substituting for $p_g(D)$ from equation (16) and noting that $\frac{\partial \bar{D}_d}{\partial p_t} = -\frac{s}{(1-\alpha)}$, the first order condition associated with the above maximization problem (upon simplification) yields (see Appendix III for a proof),

$$z - p_t = (D^+ - \bar{D}_d)\frac{(1-\alpha)}{s}$$

Since the right hand side is positive, the optimal form of intervention involves pricing traditional seeds, once again, below their associated marginal cost. By substituting for $\bar{D}_d$ into the first order condition above, and rearranging yields

$$p_t = \frac{1}{2}\left((z+w) - \frac{D^+(1-\alpha)}{s} - \frac{p_x\delta}{s}\right)$$

Coverage of GM seeds when the government is credible is hence given by,

$$\begin{aligned} \bar{D}_d^C &= \frac{(p_g - p_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)} \\ &= \frac{1}{2}\left(D^+ + \frac{(w-z)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}\right) \end{aligned} \tag{17}$$

Similarly, from the first order condition of welfare maximization above, the optimal subsidy to the per-unit price of traditional seeds by a credible government, ϕ_d^C, is solved as:

$$\phi_d^C = z - p_t = \frac{1}{2}\left(\frac{D^+(1-\alpha)}{s} - (w-z) + \frac{p_x\delta}{s}\right) \tag{18}$$

As should be evident from equation (18) the optimal price subsidy rises with (i) an increase in p_x, (ii) an increase in the marginal cost of producing traditional seeds, (z) and (iii) an increase in the range of pest pressure, $(D^+ - 0)$. On the other hand, ϕ_d^C decreases with an increase in (i) the marginal cost of producing GM seeds (w), and (ii) seed requirement, (s). The intuition for these results is along the lines discussed for the first-best regime under uniform pricing.

Second-Best Regime: Suppose that the domestic government reneges and refuses to pay the subsidy. Let the price of traditional seeds without the subsidy equal $\tilde{p}_t > p_t^e$. Correspondingly, the marginal producer in this case is now determined by

$$\tilde{D}_d = \frac{(p_g - \tilde{p}_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}$$

It is easy to check that since $\tilde{p}_t > p_t^e \Leftrightarrow \tilde{D}_d < \bar{D}_d$. As Figure IV shows, $[\bar{D}_d - \tilde{D}_d]$ fraction of producers shift to the use of GM seeds once the government reneges on its announced price of traditional seeds. Thus for $\forall D \in [\tilde{D}_d, \bar{D}_d]$ the monopolist charges $p_g(D, \tilde{P}_t) = \frac{D(1-\alpha)}{s} + \frac{p_x\delta}{s} + \tilde{p}_t$. The demand for GM seeds for this group of producers is given as $N \int_{\tilde{D}_d}^{\bar{D}_d} sd\Sigma(D)$. Therefore, total seed demand for GM seeds, in the event the domestic government is non-credible is given by,

$$N \int_{\bar{D}_d}^{D^+} sd\Sigma(D) + N \int_{\tilde{D}_d}^{\bar{D}_d} sd\Sigma(D)$$

And the monopolist's profit is

$$\tilde{\Pi}_d = N \int_{\bar{D}_d}^{D^+} \left(\frac{(p_g(D) - w)s}{D^+} \right) dD + N \int_{\tilde{D}_d}^{\bar{D}_d} \left(\frac{(p_g(D) - w)s}{D^+} \right) dD$$

We now turn to the government's problem of choosing $\tilde{p}_t$ to maximize the sum of total producer surplus and net revenue from the sale of traditional seeds, V_d,

$$\begin{aligned} \max_{\tilde{p}_t} V_d &= N \int_{\bar{D}_d}^{D^+} \left(\Omega - \alpha D^i - p_g(D, p_t^e)s + p_x\delta \right) d\Sigma(D) \\ &+ N \int_{\tilde{D}_d}^{\bar{D}_d} \left(\Omega - \alpha D^i - p_g(D, \tilde{p}_t)s + p_x\delta \right) d\Sigma(D) \\ &+ N \int_0^{\tilde{D}_d} \left(\Omega - D^i - \tilde{p}_t s \right) d\Sigma(D) + N \int_0^{\tilde{D}_d} (\tilde{p}_t - z) sd\Sigma(D) \end{aligned}$$

where $N \int_{\bar{D}_d}^{D^+} (\Omega - \alpha D^i - p_g(D, p_t^e)s + p_x\delta) \, d\Sigma(D)$ is the total surplus of producers using GM seeds; $N \int_{\tilde{D}_d}^{\bar{D}_d} (\Omega - \alpha D^i - p_g(D, \tilde{p}_t)s + p_x\delta) \, d\Sigma(D)$ is the total surplus of producers using GM seeds *if* the government reneges. Note that $\tilde{D}_d$ is variable and depends on the government's choice of $\tilde{p}_t$. $N \int_0^{\tilde{D}_d} (\Omega - D^i - \tilde{p}_t s) \, d\Sigma(D)$ is the total surplus of producers using traditional seeds and $N \int_0^{\tilde{D}_d} (\tilde{p}_t - z) sd\Sigma(D)$ is the net revenue from the sale of traditional seeds. Substituting for $p_g(D, \tilde{p}_t)$ and noting that $\frac{\partial \tilde{D}_d}{\partial \tilde{p}_t} = -\frac{s}{(1-\alpha)}$, the first order condition associated with the above maximization problem, upon simplification, yields

$$\begin{aligned} \frac{dV_d}{d\tilde{p}_t} &= \frac{(\tilde{p}_t - p_t^e)s}{(1-\alpha)} + \frac{(\tilde{p}_t - z)s}{(1-\alpha)} = 0 \\ &\Rightarrow (\tilde{p}_t - p_t^e) = -(\tilde{p}_t - z) \\ &\Rightarrow \tilde{p}_t = p_t^e = \frac{(p_t^e + z)}{2} \end{aligned}$$

Note that $\frac{(p_t^e + z)}{2} < (p_t^e + z)$ if $p_t^e > z$ and $\frac{(p_t^e + z)}{2} > (p_t^e + z)$ if $p_t^e < z$. In either of these cases, the optimal strategy is to price traditional seeds closer to the associated marginal cost, z. Thus, under rational expectation, $\tilde{p} = p_t^e = \frac{(p_t^e + z)}{2} \Rightarrow p_t^e = z$. Substituting for $p_t = z$ we have

$$\tilde{D}_d^{NC} = \frac{(w-z)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)} \tag{19}$$

Note from a comparison of equations (17) and (19), that coverage of GM is greater when the government is credible, only if

$$\bar{D}_d^C < \tilde{D}_d^{NC} \Leftrightarrow \frac{1}{2}\left(\frac{(w-z)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)} - D^+\right)$$

a sufficient condition for which is either (i) $(w-z)s$ is large or (ii) $p_x\delta$ and the range of pest pressure, $(D^+ - 0)$ are small.

Furthermore, note that comparison of equations (13) and (18) shows that for a credible government the optimal price subsidy to traditional seeds is greater when the monopolist practices perfect discrimination as compared to when the monopolist prices uniformly, since

$$\phi_d^C = \frac{1}{2}\left(\frac{D^+(1-\alpha)}{s} - (w-z) + \frac{p_x\delta}{s}\right) > \frac{1}{3}\left(\frac{D^+(1-\alpha)}{s} - (w-z) + \frac{p_x\delta}{s}\right) = \phi_u^C$$

Second, comparison of equations (12) and (17) shows that coverage of GM if the government is credible and the monopolist practices perfect discrimination is lower as compared to the case when the monopolist prices uniformly only if,

$$\bar{D}_u^C - \bar{D}_d^C = \frac{1}{6}\left(D^+ - \frac{(w-z)s}{(1-\alpha)} + \frac{p_x\delta}{(1-\alpha)}\right) < 0$$

a sufficient condition for which is that is either (i) $(w-z)s$ is large or (ii) $p_x\delta$ and the range of pest pressure, $(D^+ - 0)$ are small. Lastly, coverage of GM if the government is non-credible and the monopolist practices perfect discrimination is lower as compared to the case when the monopolist prices uniformly (comparison of equations (15) and (18)), only if

$$\bar{D}_u^{NC} - \tilde{D}_d^{NC} = \frac{1}{2}\left(D^+ - \frac{(w-z)s}{(1-\alpha)} + \frac{p_x\delta}{(1-\alpha)}\right) < 0$$

a sufficient condition for which is is either (i) $(w-z)s$ is large or (ii) $p_x\delta$ and the range of pest pressure, $(D^+ - 0)$ are small.

5 Transfers

In this section we consider the pricing of GM and traditional seeds if the government is able to obtain a license from the patent holder with the right to distribute GM seeds domestically. Of course, the first question that arises is whether a positive transfer exists from the government to the patent holder such that the licensor can be compensated for the forgone monopoly rent, while still enabling domestic welfare gains. Furthermore, we analyze how far the possibility of a transfer depends on whether the monopolist has imperfect or perfect information regarding the production conditions. We once again start with the case where the monopolist has imperfect information and hence prices GM seeds uniformly. In what follows, we shall only consider the case where the government *does not* have discretionary power to intervene in the market for traditional seeds, and hence traditional seeds are priced at marginal cost.

Let p_t^u and p_g^u denote the prices of traditional and GM seeds when the government does not have the right to distribute GM domestically. We have then,

$$\begin{aligned} p_t^u &= z \\ p_g^u &= \frac{1}{3}\frac{D^+(1-\alpha)}{s} + \frac{2}{3}w + \frac{1}{3}z + \frac{1}{3}\frac{p_x\delta}{s} \end{aligned}$$

and

$$\bar{D}_u = \frac{(p_g - p_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}$$

Now suppose that the government has the ownership of the right to sell GM seeds domestically. Let the government in this case charge p_g^* and p_t^* respectively by maximizing the welfare, V^*, which equals the sum of producers' surplus, the net revenue from the sale of traditional seeds and the surplus from selling GM seeds to the domestic producers. Thus,

$$\begin{aligned} \max_{p_t^*;\, p_g^*} \ V^* &= N\int_{D^*}^{D^+} \left(\Omega - \alpha D^i - p_g^* s + p_x\delta\right) d\Sigma(D) + N\int_0^{D^*} \left(\Omega - D^i - p_t^* s\right) d\Sigma(D) \\ &\quad + N\int_0^{D^*} (p_t^* - z)s d\Sigma(D) + N\int_{D^*}^{D+} (p_g^* - w)s d\Sigma(D) \\ &= V_u(p_g^*,\ p_t^*) + \Pi_u(p_g^*,\ p_t^*) \end{aligned}$$

where

$$D^* \equiv \frac{(p_g^* - p_t^*)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}$$

The first order conditions associated with the above maximization problem yields,

$$\begin{aligned}\frac{\partial V^*}{\partial p_t^*} = \frac{(p_t^* - z)s}{(D^+}\frac{\partial D^*}{\partial p_t^*} - \frac{(p_g^* - w)s}{D^+}\frac{\partial D^*}{\partial p_t^*} &= 0 \\ \frac{\partial V^*}{\partial p_g^*} = \frac{(p_t^* - z)s}{D^+}\frac{\partial D^*}{\partial p_g^*} - \frac{(p_g^* - w)s}{D^+}\frac{\partial D^*}{\partial p_g^*} &= 0\end{aligned}$$

which implies that $p_t^* = z$ and $p_g^* = w$. Thus, the government will practice marginal cost pricing for both GM and traditional seeds.

Since p_g^* and p_t^* maximizes $V^* = V_u(p_g^* = w,\ p_t^* = z) + \Pi_u(p_g^* = w,\ p_t^* = z)$ it must be the case that $V^* \geq V_u(p_g^u,\ p_t^u = z) + \Pi_u(p_g^u,\ p_t^u = z)$ or that $V^* - \Pi_u(p_g^u,\ p_t^u = z) \geq V_u(p_g^u,\ p_t^u = z)$. Consequently, welfare of the developing economy after transferring ownership and repayment of monopoly profits is higher than the welfare of the economy without transferring ownership.
Thus, $T^u \in [V^*(p_g^* = w,\ p_t^* = z) - \Pi_u(p_g^u,\ p_t^u = z);\ \ V_u(p_g^u,\ p_t^u = z)]$ identifies the range within which the size of the transfer belongs.

We now turn to the possibility of transfers when the monopolist has perfect information (perfect discrimination). Once again if the government has ownership to distribute GM then p_g^* and p_t^* are selected via the optimization of,

$$\begin{aligned}\max_{p_t^*;\, p_g^*}\ V^* &= N\int_{D^*}^{D^+}\left(\Omega - \alpha D^i - p_g^* s + p_x\delta\right)d\Sigma(D) + N\int_0^{D^*}\left(\Omega - D^i - p_t^* s\right)d\Sigma(D) \\ &\quad + N\int_0^{D^*}(p_t^* - z)s\,d\Sigma(D) + N\int_{D^*}^{D+}(p_g^* - w)s\,d\Sigma(D)\end{aligned}$$

If the government sets $p_g^* = w$ and $p_t^* = z$, then V^* above reduces to,

$$V^* = N\int_{D^*}^{D^+}\left(\Omega - \alpha D^i - ws + p_x\delta\right)d\Sigma(D) + N\int_0^{D^*}\left(\Omega - D^i - zs\right)d\Sigma(D)$$

Now, consider the welfare of the developing economy when the monopolist is able to perfectly price discriminate (V_d) with $p_g = \frac{D(1-\alpha)}{s} + \frac{p_x\delta}{s} + p_t$ and $p_t = z$. Thus,

$$\begin{aligned}\max_{p_t^*}\ V_d &= N\int_{\bar{D}_d}^{D^+}\left(\Omega - \alpha D^i - p_g s + p_x\delta\right)d\Sigma(D) + N\int_0^{\bar{D}_d}\left(\Omega - D^i - p_t s\right)d\Sigma(D) \\ &\quad + N\int_0^{\bar{D}_d}(p_t - z)s\,d\Sigma(D) \\ &= N\int_{\bar{D}_d}^{D^+}\left(\Omega - D^i - zs\right)d\Sigma(D) + N\int_0^{\bar{D}_d}\left(\Omega - D^i - zs\right)d\Sigma(D)\end{aligned}$$

On the other hand, the profit of the monopolist under perfect discrimination with $p_g = \frac{D(1-\alpha)}{s} + \frac{p_x \delta}{s} + p_t$ and $p_t = z$ equals

$$\begin{aligned}
\Pi_d &= N \int_{\bar{D}_d}^{D^+} (p_g(D) - w) s d\Sigma(D) \\
&= N \int_{\bar{D}_d}^{D^+} \left(\Omega - \alpha D^i - ws + p_x \delta\right) d\Sigma(D) - N \int_{\bar{D}_d}^{D^+} \left(\Omega - D^i - zs\right) d\Sigma(D)
\end{aligned}$$

Thus, if $\bar{D}_d = \frac{(w-z)s}{(1-\alpha)} + \frac{p_x \delta}{(1-\alpha)} = D^*$, then

$$\begin{aligned}
V_d(p_g, p_t = z) + \Pi_d(p_g, p_t = z) &= N \int_{D^*}^{D^+} \left(\Omega - \alpha D^i - ws + p_x \delta\right) d\Sigma(D) \\
&\quad + N \int_0^{D^*} \left(\Omega - D^i - zs\right) d\Sigma(D) \\
&\equiv V^*(p_g^* = w, p_t^* = z)
\end{aligned}$$

which shows that if the monopolist perfectly discriminates then $V^* = V_d + \Pi_d$ or $V^* - \Pi_d \equiv V_d$. There does not exist any positive transfer that leads to the welfare of the developing economy being *strictly* better-off if the government buys the right of ownership to distribute GM seeds domestically.

6 Conclusion

As opposed to the recent focus in the literature on the pricing of GM seeds contingent upon the strength of IPR enforcement, we analyze the role governments can play in order to ensure that the monopolist supplier of GM seeds is unable to extract a higher than optimal surplus from domestic producers in the agrarian economy of developing countries. This is particularly relevant against the background of widespread public concerns that poor farmers might be exploited through multinational companies.

We use the example of pest-resistant GM crops. By endogenizing the technology adoption decision of heterogeneous producers, we emphasize not only the range of pricing options for the government and the foreign monopolist but also the resulting technology coverage. We show that the optimal form of intervention for the government wishing to increase GM coverage and maximize domestic welfare is to subsidize the price of traditional seeds. This counter-intuitive result follows from recognizing that GM and traditional seeds are (imperfect) substitutes. Hence, lowering the price of traditional seeds forces the monopolist to reduce the price of GM seeds in order to preserve market share. The optimal size of the traditional seed subsidy depends systematically on the (i) intensity of seed usage (GM and traditional), (ii) marginal cost of GM and traditional seeds, (iii) price of chemical pesticides, (iv) degree to which GM seeds increase productivity, and (v) range of pest pressure among farmers.

We also identify a set of conditions under which coverage of GM can be evaluated for the two information cases. For instance, if the seed requirement per unit of land or the difference between the marginal costs of producing GM and traditional seeds are large and/or the price of the pesticide input and the range of pest pressure on land are small then (i) coverage of GM under a credible intervention through a subsidy to traditional seeds is higher irrespective of whether the monopolist practices uniform or discriminatory pricing, as compared to the situation where traditional seeds are priced at marginal cost and (ii) coverage of GM under uniform pricing by the monopolist is higher as compared to the case where the monopolist can price-discriminate irrespective of whether the government can credibly intervene in the domestic seed market. Nonetheless, our findings pinpoint time-inconsistency of government policies as a possible reason for sub-optimal coverage of GM seeds in developing countries.

Finally, we consider the option of the government obtaining the ownership right to distribute GM seeds domestically through a transfer to the monopolist. Under uniform pricing of GM seeds, there exists a transfer that leads to a higher level of domestic welfare by allowing the government to practice marginal cost pricing for both GM and traditional seeds. However, when the monopolist can practice perfect discrimination, the possibility of a strictly welfare improving transfer does not exist.

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Appendix

I. Best-Response function of the Monopolist under Uniform Pricing.

The monopolist's profit maximization problem is given by

$$\max_{p_g} \;\; \Pi_u(p_g,\; p_t^e) = N\int_{\bar{D}_u}^{D^+} \frac{(p_g-w)s}{D^+}dD = \frac{N}{D^+}(p_g-w)s[D^+ - \bar{D}_u]$$

Therefore,

$$\frac{d\Pi_u}{dp_g} = \frac{N}{D^+}(p_g-w)s(-\frac{d\bar{D}_u}{dp_g}) + \frac{N}{D^+}s[D^+ - \bar{D}_u] = 0$$

Since

$$\bar{D}_u \equiv \frac{(p_g-p_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}$$

and $\frac{d\bar{D}_u}{dp_g} = \frac{s}{(1-\alpha)}$, substituting above yields,

$$\frac{d\Pi_u}{dp_g} = \frac{N}{D^+}\left(\frac{-2p_g s^2}{(1-\alpha)} + D^+ s + \frac{ws^2}{(1-\alpha)} + \frac{p_t s^2}{(1-\alpha)} + \frac{p_x\delta s}{(1-\alpha)}\right) = 0$$

which upon simplification yields

$$p_g = \frac{1}{2}\left(\frac{(1-\alpha)D^+}{s} + (p_t+w) + \frac{p_x\delta}{s}\right)$$

II. Welfare Maximization under Uniform Pricing — First-Best Regime.

The welfare maximization problem of the developing country government is given by

$$\begin{aligned}\max_{p_t} \;\; V_u \;\; &= \;\; N\int_{\bar{D}_u}^{D^+}\left(\Omega - \alpha D^i - p_g s + p_x\delta\right)d\Sigma(D) + N\int_0^{\bar{D}_u}\left(\Omega - D^i - p_t s\right)d\Sigma(D)\\ &\quad + N\int_0^{\bar{D}_u}(p_t - z)s d\Sigma(D)\end{aligned}$$

Therefore,

$$\begin{aligned}\frac{dV_u}{dp_t} \;\; &= \;\; N\int_{\bar{D}_u}^{D^+}\frac{-1}{2}\frac{s}{D^+}dD - N\int_0^{\bar{D}_u}\frac{s}{D^+}dD + N\int_0^{\bar{D}_u}\frac{s}{D^+}dD\\ &\quad + \frac{N}{D^+}\left(\Omega - \alpha\bar{D}_u - p_g s + p_x\delta\right)(-\frac{d\bar{D}_u}{dp_t}) + \frac{N}{D^+}\left(\Omega - \bar{D}_u - p_t s\right)(\frac{d\bar{D}_u}{dp_t})\\ &\quad + \frac{N}{D^+}(p_t - z)s(\frac{d\bar{D}_u}{dp_t}) = 0\end{aligned}$$

Substituting for $\frac{d\bar{D}_u}{dp_t} = -\frac{1}{2}\frac{s}{(1-\alpha)}$ and on simplification yields,

$$\begin{aligned}\frac{dV_u}{dp_t} \;\; &= \;\; -\frac{1}{2}\frac{Ns}{D^+}[D^+ - \bar{D}_u] - \frac{1}{2}\frac{Ns}{D^+(1-\alpha)}(p_t - z)s\\ &\quad -\frac{1}{2}\frac{Ns}{D^+(1-\alpha)}\left((1-\alpha)\bar{D}_u - p_g s + p_t s + p_x\delta\right) = 0\end{aligned}$$

Since $\bar{D}_u \equiv \frac{(p_g-p_t)s}{(1-\alpha)} - \frac{p_x\delta}{(1-\alpha)}$, the last term in the above equation vanishes. Thus, we have

$$\begin{aligned} -[D^+ - \bar{D}_u] - \frac{(p_t-z)s}{(1-\alpha)} &= 0 \\ \Rightarrow \frac{(D^+ - \bar{D}_u)(1-\alpha)}{s} &= z - p_t \end{aligned}$$

III. Welfare Maximization under Perfect Discrimination — First-Best Regime.

The welfare maximization problem of the developing country government in this case is given by

$$\begin{aligned} \max_{p_t} \; V_d &= N\int_{\bar{D}_d}^{D^+} \left(\Omega - \alpha D^i - p_g(D,p_t)s + p_x\delta\right) d\Sigma(D) + N\int_0^{\bar{D}_d} \left(\Omega - D^i - p_t s\right) d\Sigma(D) \\ &\quad + N\int_0^{\bar{D}_d} (p_t - z)s d\Sigma(D) \end{aligned}$$

Substituting for $p_g = \frac{(1-\alpha)D}{s} + \frac{p_x\delta}{s} + p_t$ yields,

$$\begin{aligned} \max_{p_t} \; V_d &= N\int_{\bar{D}_d}^{D^+} \left(\frac{\Omega - D^i - p_t s}{D^+}\right) dD + N\int_0^{\bar{D}_d} \left(\frac{\Omega - D^i - p_t s}{D^+}\right) dD \\ &\quad + N\int_0^{\bar{D}_d} \frac{(p_t-z)s}{D^+} dD \end{aligned}$$

The first order condition is given by

$$\begin{aligned} \frac{dV_d}{dp_t} &= \frac{N}{D^+}\left(\Omega - \bar{D}_d - p_t s\right)\left(-\frac{d\bar{D}_d}{dp_t}\right) + \frac{N}{D^+}\left(\Omega - \bar{D}_d - p_t s\right)\left(\frac{d\bar{D}_d}{dp_t}\right) \\ &\quad - \frac{N}{D^+}s[D^+ - \bar{D}_d] - \frac{N}{D^+}s\bar{D}_d + \frac{N}{D^+}s\bar{D}_d + \frac{N}{D^+}(p_t - z)s\left(\frac{d\bar{D}_d}{dp_t}\right) = 0 \end{aligned}$$

substituting for $\frac{d\bar{D}_d}{dp_t} = -\frac{1}{2}\frac{s}{(1-\alpha)}$ yields,

$$(z - p_t) = [D^+ - \bar{D}_d]\frac{(1-\alpha)}{s}$$

Table 1: Summary statistics and model results

	Summary statistics (*n* = 289)		Results of WTP model (*n* = 289)	
Variable	**Mean**	**Std. Dev.**	**Coefficient**	**t-statistic**
Land owned (ha)	245.39	716.09	0.05	3.39
Square of land owned	571,226	3,778,288	-7.4×10^{-6}	-3.16
Education (years)	6.70	3.73	2.73	2.49
Age (years)	48.70	11.35	-0.08	-0.27
Credit constraint (dummy)	0.77	0.42	-19.31	-2.70
Insecticide expenditure ($/ha)	15.95	14.27	0.60	2.44
Good soil quality (dummy)	0.25	0.43	10.00	1.45
Price of traditional seed ($/ha)	14.40	8.72	1.46	2.74
Constant			27.95	1.38
Log likelihood			-189.90	

Figure I: Willingness to Pay for GM

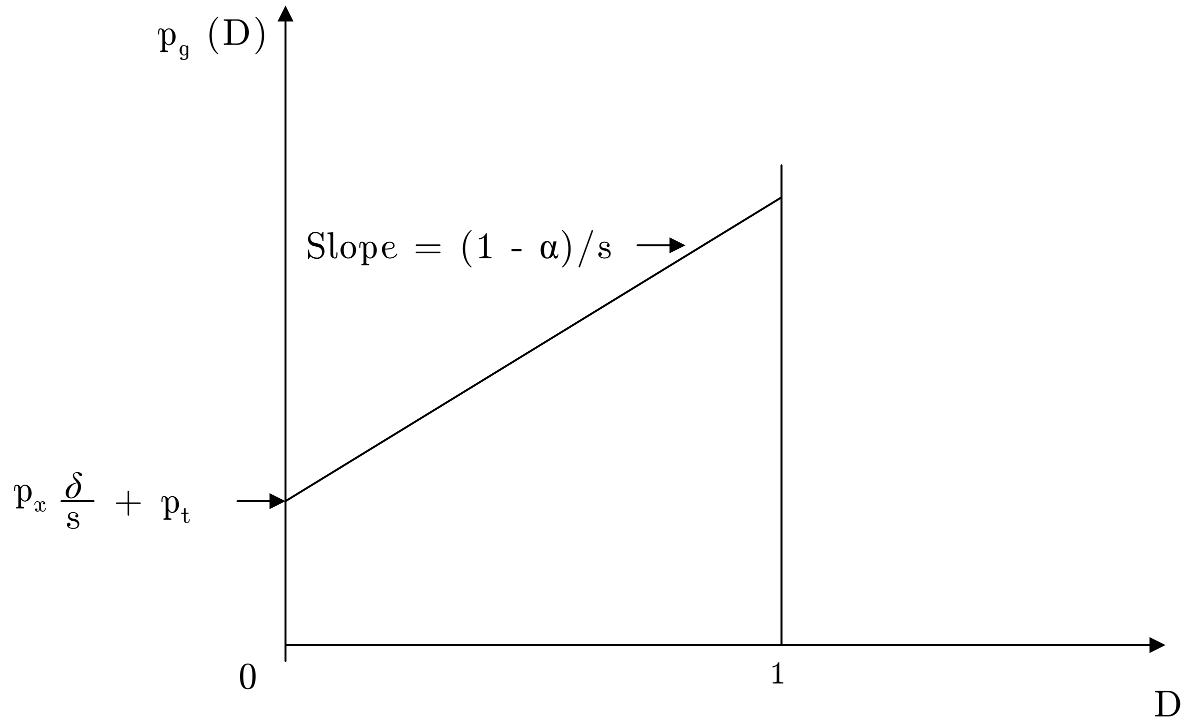


Figure II: Uniform Pricing,
Credible Government

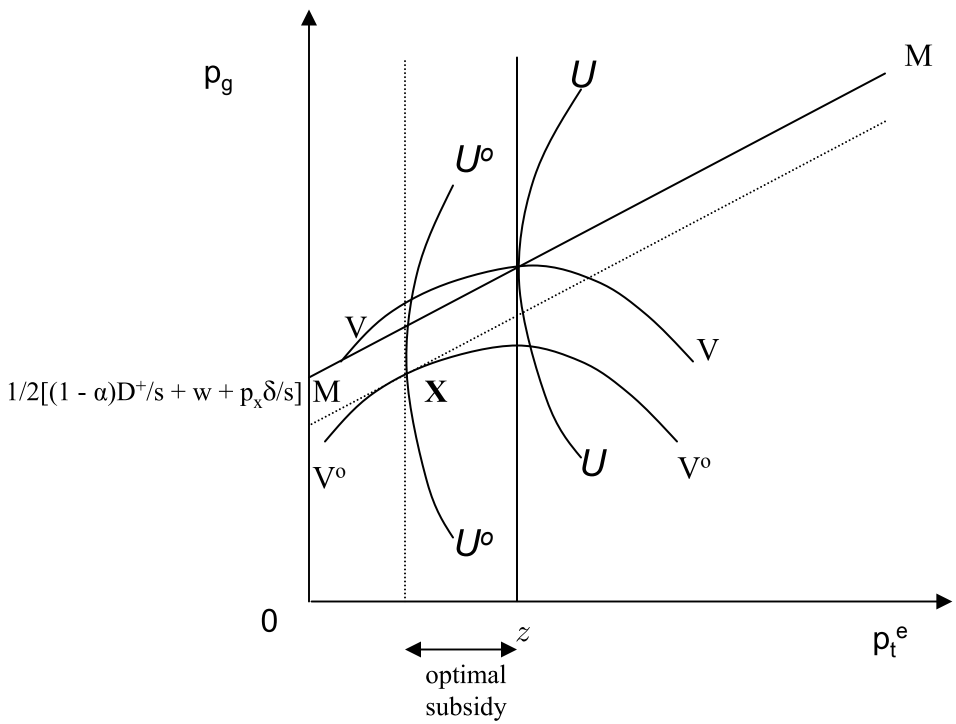


Figure III: Uniform Pricing, Non-Credible Government

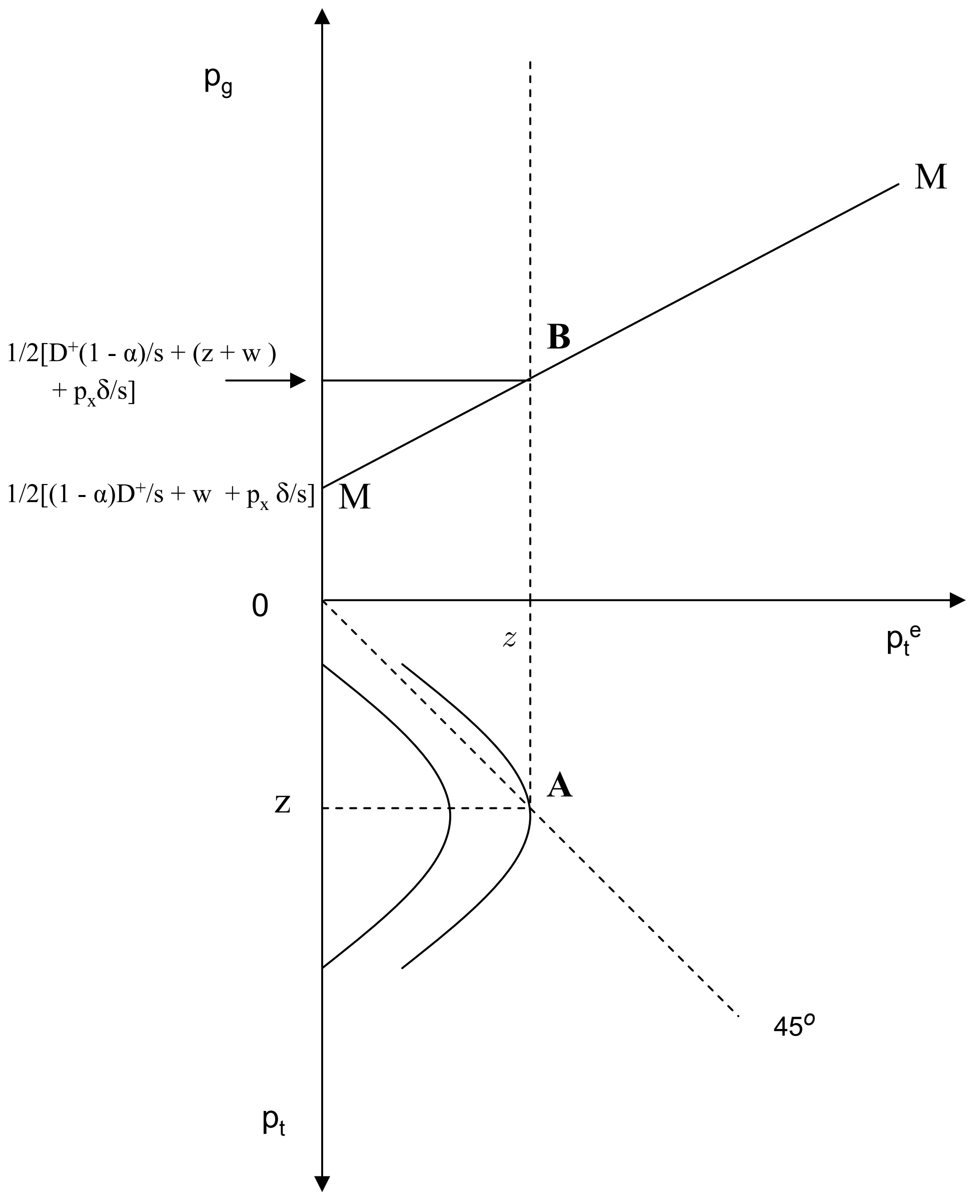
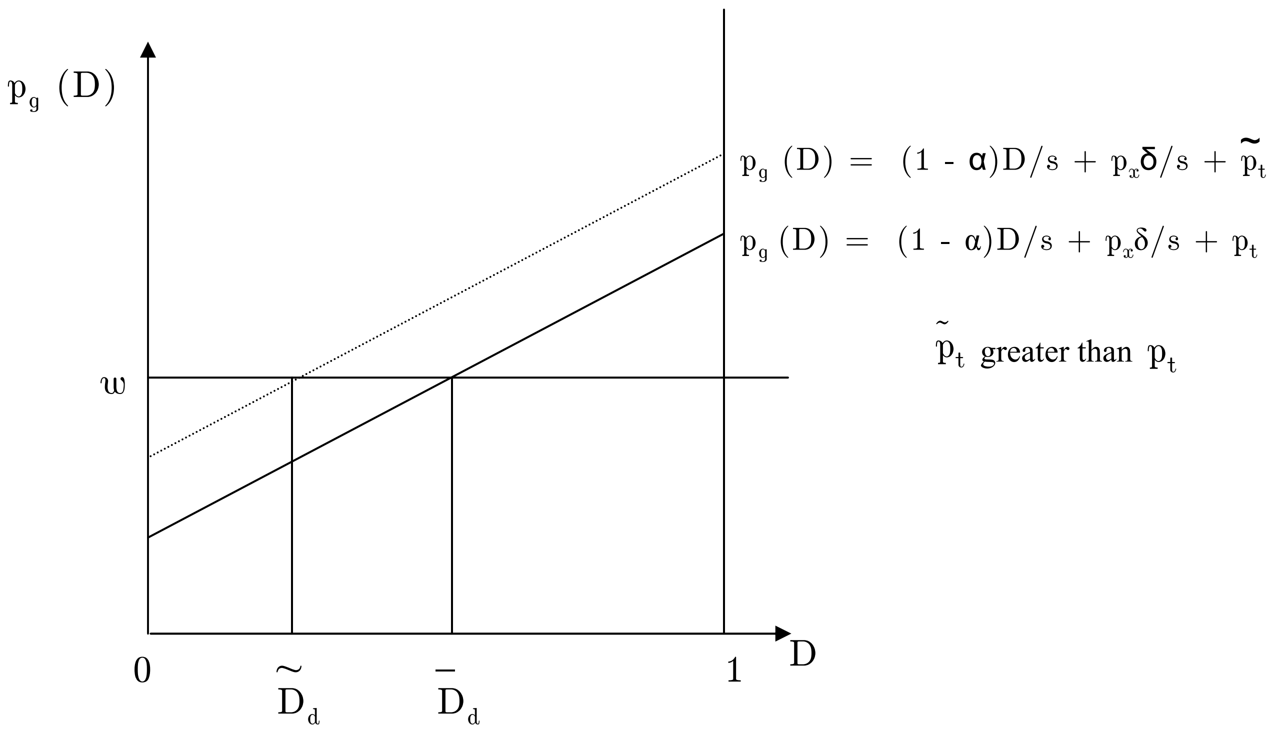


Figure IV: Producers' Self-Selection
Perfect Discrimination, Non-Credible Government



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