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Pricing, Distribution and Adoption of Genetically Modified Seeds under Alternative Information Regimes

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Abstract

This paper considers genetically modified (GM) seed adoption decisions by farmers in a developing country under two alternative information regimes (with and without perfect information regarding production conditions) that allows the monopolist producer of GM seeds to either practice perfect discrimination or uniform pricing. Under each regime we analyze two scenarios: when the government can and cannot credibly commit to the announced form of welfare enhancing intervention in the domestic seed market. We show that the optimal policy under either information regime is to subsidize the price of *conventional* seeds. The optimal size of the conventional seed subsidy depends systematically, in turn, on the (i) marginal cost of GM and conventional seeds, (ii) price of chemical pesticides, (iii) degree to which GM seeds increase productivity, (iv) range of pest pressure among farmers, and (v) intensity of seed usage (GM and conventional). Nonetheless, our findings pinpoint time-inconsistency of government policies as a possible reason for sub-optimal coverage of GM seeds in developing countries.

Kurzfassung

Diese Arbeit untersucht Entscheidungsstrategien von Bauern hinsichtlich der Anwendung genetisch veränderten Saatguts (genetically modified, GM) in zwei Entwicklungsländern mit unterschiedlichen Informationssystemen (mit und ohne Informationen über die Produktionsbedingungen), die es dem Monopolisten-Erzeuger von GM Saatgut erlauben, entweder perfekte Diskriminierung zu praktizieren oder einheitliche Preissysteme zu etablieren. Innerhalb jedes Informationssystems analysieren wir zwei Szenarien: Ob die Regierung in der Lage ist oder nicht, sich glaubwürdig zu der angekündigten, wohlfahrtssteigernden Form der Intervention auf dem heimischen Saatgutmarkt zu verpflichten. Wir zeigen, dass die optimale Verfahrensweise in jedem Informationssystem eine Subvention des Preises konventioneller Samen ist. Die ideale Höhe der konventionellen Saatgutsubvention hängt systematisch davon ab, (i) wie hoch die Grenzkosten der GM und des konventionellen Saatguts sind, (ii) wie hoch die Kosten für die chemischen Pestizide sind, (iii) in welchem Maß GM die Produktivität erhöhen, (iv) wie sehr die Pflanzungen von Schädlingen befallen werden und (i) wie hoch die Intensität des Saatgutgebrauchs ist (GM und konventionell). Trotzdem zeigen unsere Untersuchungen genau auf, dass die zeitliche Unbeständigkeit der jeweiligen Regierungsstrategie ein Grund für die sub-optimale Verbreitung der GM Samen in Entwicklungsländern sein können.

1 Introduction

Biotechnological breakthroughs over the last decade in the area of genetically modified (GM) seeds have been hailed as the next Green Revolution. The ability of GM seeds to reduce pesticide use and increase yields for a variety of crops has enabled small and large scale farmers alike to reap benefits across all continents. However, the adoption of GM seeds is not without controversy. There are claims that GM crop varieties have the potential to adversely affect biodiversity through cross-pollination with conventional varieties of seeds as well as the possibility of health hazards associated with the consumption of GM food. Nevertheless, while further risk studies are necessary, worrying negative environmental or health externalities of commercial GM crop applications have not occurred up till now.

Regarding the benefits of GM seed adoption, field studies by Pray, Huang, Hu and Rozelle (2002) show for cotton in China, and Qaim and Traxler (2005) 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 (2003b) and Thirtle, Beyers, Ismael, and Piesse (2003) further reveal that GM crops can also increase yields in situations where pesticides are underused. As a consequence, in this paper, we focus on the potential benefits of GM seed adoption and explore the pricing and adoption decision of farmers in developing countries under alternative information regimes.

As a starting point, it is worthwhile to provide a brief background on the development and distribution of GM seeds. Research and development (R & D) of GM seeds is dominated by a few multinational companies that hold proprietary rights over GM seed development and distribution. For instance, 96% of funding sources for biotechnology investments occur in the industrialized countries and of the 96%, 70% of the funding comes from private sources. Developing countries constitute only 4% of the global investment in biotechnology research with China as a leader followed by India and Brazil (James 2002; Acquaye and Traxler 2005). Given proprietary rights of private seed companies in the industrialized countries, the promise of GM crops in raising productivity and hence income of small scale and marginal farmers in developing countries hinges crucially on the availability of GM seeds at affordable prices. As Qaim and de Janvry (2003a) show for Bt (Bacillus thuringiensis) cotton in Argentina, the prevalence of a high monopoly price for GM seeds is a major barrier to adoption, especially for smallholder farmers.

The high price of GM seeds is a direct consequence of strengthened intellectual property rights (IPR) protection accorded to patent holders of GM technology in developed, but increasingly also in developing countries[1]. Furthermore, improved monitoring technologies facilitate spotting of illegal seed usage and partly even allow monopolists to price discriminate their technologies. Biotech companies had partly implemented regional price discrimination for Bt seeds in the US, but in developing countries lack of adequate information regarding production conditions had led them mostly to practice uniform pricing for GM seeds. However, recent evidence shows that some form of price discrimination also exists for Bt cotton seeds in Mexico and South Africa (Traxler et al. 2003; Gouse, Pray, and Schimmelpfennig 2004). In South Africa, for instance, Monsanto and Delta & Pineland charge large-scale farmers (who produce under both irrigated and dry land conditions) around US$86 and small-scale farmers (who produce exclusively under dry land conditions) US$33 per 25kg bag of seeds. As Gouse, Pray, and Schimmelpfennig (2004) point out, price discrimination is aided by the non-existence of arbitrage selling from small to large-scale farmers since different farmer groups purchase GM seeds in different outlets and transportation costs are significant in South Africa. Needless to say, both stronger IPRs and price discrimination allow for a larger transfer of the benefits from GM seed adoption from farmers in developing countries to the patent holders of GM technology.

In this paper, we account for these two developments and focus on the issue of pricing, distribution and adoption of GM seeds under two alternative information regimes: with and without perfect information on the part of the foreign monopolist regarding production conditions. For each of these two information regimes, we derive the optimal form of intervention in the seed market by the government of a developing country to maximize domestic welfare. We further underscore two scenarios within each information regime: where a developing country government may or may not be able to credibly commit to the 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. This latter aspect of our model allows for a comparison of GM seed adoption both within and across information regimes. Noteworthy here is the fact that the comparative-statics of a credible intervention under alternative information regimes on GM seed adoption has yet to receive attention in the literature which has been focused primarily on: (i) the incentives affecting R & D decisions for GM seeds (Weaver and Kim, 2002) and (ii) the effect of IPR enforcement on pricing and adoption decisions (Giannakas, 2002; Chattopadhyay and Horbulyk, 2003; Basu and Qaim, 2007).

Weaver and Kim's (2002) study is based on the notion that 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., conventional seeds and chemical

[1] It is worth noting that for most of the early GM applications in developing countries, farmers' access to GM technology was not a problem, because IPRs were either non-existent or not effectively enforced. The prevalence of a market for illegally obtained GM seeds limited monopoly power and kept GM seed prices relatively low, as foreign innovators competed for market share not only with conventional seed suppliers, but also with black market traders.

regimes). Given this limited monopoly power, and under imperfect information regarding production conditions on the part of the patent holder, uniform pricing of GM seeds results in the appropriation of large parts of the benefits by the adopters. In terms of IPRs, Giannakas (2002) 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 (2003) 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 conventional seeds is consistent with welfare maximization of the adopting country. Nevertheless, either of these two policies reduce coverage of GM seeds in Chattopadhyay and Horbulyk's model. Basu and Qaim (2007) show that the optimal level of IPR enforcement under uniform pricing of GM seeds should be zero, and that a subsidy towards conventional seed prices or a lump-sum transfer to the foreign monopolist (GM seed supplier) to obtain the rights of GM seed distribution enhances domestic welfare in a developing country.

As a starting point, we abstract from the issue of IPR infringements and the presence of any externalities subsequent upon the decision to adopt GM seeds by farmers[2]. We model the foreign monopolist supplier of GM seeds as a restrictive monopolist `a la Weaver and Kim due to the existence of a competing conventional seed market which imposes an upper bound on the price that the monopolist can charge. We consider a small open economy in the absence of labeling (thus ruling out the possibility of an output-price differential) where the government of this economy intervenes by maximizing the sum of producers' surplus and net revenue from the sale of conventional 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 under either information regime.

The basic framework[3] explores a sequential game between the foreign monopolist GM seed supplier and the government to determine the prices of GM and conventional 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 conventional seed market by maximizing domestic welfare. Subsequently, the monopolist, by accounting for the possibility that the government's announced policy might be time-inconsistent, sets the price

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[2] 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.

[3] The basic framework in this model follows that of Basu and Qaim (2007) with a major caveat. Unlike Basu and Qaim, we have perfect enforcement of IPRs and hence the absence of an illegal GM seed market in the developing country. Moreover, Basu and Qaim do not address the issue of perfect discrimination and credible commitment of government policies.

of GM seeds. Finally, the heterogeneous producers self-select into the usage of either GM or conventional seeds. In a scenario where (i) IPR infringement is a non-issue, (ii) GM seeds are priced higher than their conventional counterpart and (iii) the government can credibly commit to the announced form of intervention, we find that for both the perfect and imperfect information case, the optimal form of intervention entails subsidizing the use of conventional seeds. This counter-intuitive result follows from recognizing the fact that GM and conventional seeds are (imperfect) substitutes as inputs in production. Subsequently, lowering the price of conventional seeds forces the monopolist GM seed supplier to reduce the price of GM seeds in order to preserve market share.

The plan of the paper is as follows: in the next section, the basic theoretical model is developed, while in section 3, the pricing strategies of GM and conventional seeds are explored under the perfect and imperfect information scenarios. The last section concludes.

2 Basic Model

The model we consider has three distinct stakeholders: (i) the monopolist GM seed supplier; (ii) producers who self-select into either of two groups – user of GM seeds or conventional ones and (iii) the government of the developing economy which undertakes the twin role of procuring conventional seeds from perfectly competitive conventional seed suppliers and selling them to the adopters of conventional 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 conventional better quality seeds are sold to adopters through an agency like the seed marketing board. Yet, assuming that conventional seeds were sold by a private domestic company would not significantly change the analytic results[4].

The economy we consider has N total producers. There are two types of technologies available to an individual producer in the economy: conventional 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 conventional seeds.

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

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

where Q_t is the output from using conventional 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 $\sigma(\mathrm{D}) > 0$ and a cumulative distribution function $\sum(\mathrm{D})$. Thus, higher values of D capture increasing pest pressure[5].

[4] While in many African countries, private sector involvement in seed development and distribution is limited, the situation is different in parts of Asia, especially in India. For commercial crops like cotton, the majority of Indian farmers purchase seeds regularly, and many of them use private sector hybrids (Qaim 2003). Even in food crops, including semi-subsistence crops, regular seed purchases are common (e.g., Ramaswami, Pray, and Kelley 2002). A recent study for pearl millet in Maharashtra, a state in India's semi-arid tropics where smallholder farming dominates, showed that 78% of the farmers use hybrid seeds, mostly from the private sector (Matuschke 2007).

[5] 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).

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

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

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 conventional ones. In other words, α is negatively correlated with the GM technology's effectiveness to control pest damage. The parameter 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 conventional 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 conventional 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 conventional seed user. Therefore,

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

where P is the price per unit output of the conventional crop; p_t is the price per unit of conventional 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,

$$\frac{\partial \pi_t}{\partial y} = PF'(y) - p_y = 0 \Rightarrow y^* = f\left(\frac{p_y}{P}\right)$$

$$\frac{\partial \pi_t}{\partial x} = PG'(x) - p_x = 0 \Rightarrow x^* = g\left(\frac{p_x}{P}\right)$$

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

$$\pi_t = P[F(y^*) + G(x^*) - D^i] - p_t s - p_x x^* - p_y y^* \tag{3}$$

$$= P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P})) - D^i] - p_t s - p_x g(\frac{p_x}{P}) - p_y f(\frac{p_y}{P})$$

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 conventional 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

$$\frac{\partial \pi_g}{\partial y} = PF'(y) - p_y = 0 \Rightarrow y^* = f(\frac{p_y}{P})$$

$$\frac{\partial \pi_g}{\partial x} = PG'(x-\delta) - p_x = 0 \Rightarrow x^* = g(\frac{p_x}{P}) - \delta$$

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

$$\pi_g = P[F(y^*) + G(x^* + \delta) - \alpha D^i] - p_g s - p_x x^* - p_y y^* \tag{4}$$

$$= P[F(f(\frac{p_y}{P})) + G(g(\frac{p_x}{P}) - \delta + \delta) - \alpha D^i] - p_g s - p_x[g(\frac{p_x}{P}) - \delta] - p_y f(\frac{p_y}{P})$$

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

$$P\left[F\left(f\left(\frac{p_y}{P}\right)\right) + G\left(g\left(\frac{p_x}{P}\right) - \delta + \delta\right) - \alpha D^i\right] - p_g s - p_x\left[g\left(\frac{p_x}{P}\right) - \delta\right] - p_y f\left(\frac{p_y}{P}\right)$$

$$\geq \quad P\left[F\left(f\left(\frac{p_y}{P}\right)\right) + G\left(g\left(\frac{p_x}{P}\right)\right) - D^i\right] - p_t s - p_x g\left(\frac{p_x}{P}\right) - p_y f\left(\frac{p_y}{P}\right)$$

Normalizing the output price of conventional 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:

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

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, $\overline{D}$, 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 conventional seed use), the more likely it is that a producer will opt for GM seeds. Thus, the number of producers who opt for conventional seeds is $N \sum(\overline{D})$ while the number of producers who opt for GM seeds is $N \; [1-\sum(\overline{D})]$.

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

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

From equation (6) above, the WTP for GM seeds is positively related to the pest pressure on land. Additionally, the WTP rises with an increase in either (i) the price of conventional 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 empirical evidence (Qaim and de Janvry, 2003; Basu and Qaim, 2007). 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.

3 Monopolist Supplier of GM Seeds and Optimal Intervention in the Conventional 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 conventional seed market. We assume the logical sequence that the government is the first mover in announcing whether it chooses to intervene in the conventional 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 conventional 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.

3.1 Uniform Pricing of GM Seeds

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 conventional 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 conventional seed use is given by

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

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

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

As shown in Appendix I, by substituting for $\overline{D}_u$ 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 $\frac{1}{2}\left(\frac{(1-\alpha)D^+}{s} + w + \frac{px\delta}{s}\right)$ and slope $\frac{1}{2}$.

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

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

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

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

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

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

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 conventional 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

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

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

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

where $N\int_{\overline{D}_u}^{D^+} \pi_g d\Sigma(D)$ is the total surplus of producers using GM seeds; $N\int_0^{\overline{D}_u} \pi_t d\Sigma(D)$ is the total surplus of producers using conventional seeds and $N\int_0^{\overline{D}_u} (p_t - z)\, sd\Sigma(D)$ is the net revenue of the government from selling conventional seeds. *z* is the marginal cost of producing conventional seeds, and with perfectly competitive conventional seed suppliers, *z* is also the procurement cost incurred by the government. The marginal costs of conventional 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,

$N\sum(D)[p_t - z]s + T = 0$

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

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

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

$$\max_{p_t} \; V_u = N\int_{\overline{D}_u}^{D^+}\left(\Omega - aD^i - p_g s + p_x\delta\right) d\sum(D) + N\int_0^{\overline{D}_u}\left(\Omega - D^i - p_t s\right) d\sum(D)$$
$$+N\int_0^{\overline{D}_u}\left(p_t - z\right) s d\sum(D)$$

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

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

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

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

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

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

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

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, $N\left[1-\sum\left(\overline{D}_u^C\right)\right]$ with

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

Finally the optimal per-unit price subsidy, $\varnothing_u^C$, on conventional seeds is given by

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

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 conventional 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, preempts this possibility by skewing the incentives for domestic producers towards the use of conventional seeds via a subsidy. An increase in the marginal cost of producing conventional seeds has the effect of raising the price of conventional 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 conventional 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

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

Therefore,

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

$$= -\frac{1}{2}\left(1 + \frac{(p_t - z)}{\left[D^+ - \overline{D}_u\right]}\frac{s}{(1-\alpha)}\right)$$

Thus,

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

In Figure II the curves *VV* plot the iso-welfare contours of the developing economy. Note from above that since $\frac{\partial V_u}{\partial_{pt}} < 0$ lower iso-welfare curves denote a *higher* level of welfare for the developing economy.[6] Under the first best regime, equilibrium is attained at point *X* where the monopolist's best-response function is tangent to the iso-welfare curve V^o, with $(z - p_t) = \varnothing_u^C$ as the per-unit level of subsidy to conventional seeds.[7]

Second-Best Regime: We now consider the optimal prices of GM and conventional 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 $\psi\left(p_t^e\right)$ be the price of conventional 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,

$$\overline{D}_u \equiv \frac{\left(p_g - p_t^e\right)s}{(1-\alpha)} - \frac{px\delta}{(1-\alpha)}$$

The government maximizes

6 $\frac{dV_u}{dp_t} = \frac{1}{2}\frac{N}{D^+}s\left(\left[D^+ - \overline{D}_u\right] + \left(p_t - z\right)\frac{s}{(1-\alpha)}\right) < 0$.

7 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.,

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

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

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

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

Or $\psi\,(p_t^e) = p_t = z$. Therefore, in the event that the government cannot commit to the announced price, conventional 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 conventional seeds. In the bottom quadrant of the Figure, the 45° line equates $p_t^e = p_t$ 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 conventional seeds are priced at marginal cost while point *B* determines the price of GM seeds when conventional 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 $N\left[1-\Sigma\left(\bar{D}_u^{NC}\right)\right]$ when the government cannot credibly commit to the announced price of conventional 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 conventional 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 conventional 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,

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

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.

3.2 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., 2004). 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

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

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, $N\int_{\overline{D}_d}^{D^+} s\, d\Sigma(D) = N\int_{\overline{D}_d}^{D^+} \frac{s}{D^+} dD$, a perfectly discriminating monopolist's profit (Π_d) is

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

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

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

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

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

First-Best Regime: Suppose the government is credible and commits to the announced price of conventional 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 conventional seed users) and net revenue from the sale of conventional seeds, V_d, by the choice of p_t as:

$$\max_{pt} V_d = N\int_{\overline{D}_d}^{D^+}\left(\Omega - \alpha D^i - p_g\left(D, p_t\right)s + p_x\delta\right)d\Sigma(D) + N\int_0^{\overline{D}_d}\left(\Omega - D^i - p_t s\right)d\Sigma(D)$$
$$+ N\int_0^{\overline{D}_d}\left(p_t - z\right)sd\Sigma(D)$$

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

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

Since the right hand side is positive, the optimal form of intervention involves pricing conventional seeds, once again, below their associated marginal cost. By substituting for $\overline{D}_d$ 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,

$$\overline{D}_d^C = \frac{\left(p_g - p_t\right)s}{(1-\alpha)} - \frac{p_x\delta}{s} \tag{17}$$

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

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

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

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 conventional seeds, (*z*) and (iii) an increase in the range of pest pressure, $(D^{+} - 0)$. On the other hand, $\varnothing_d^C$ 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 conventional 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, $\left[\bar{D}_d - \tilde{D}_d\right]$ fractions of producers shift to the use of GM seeds once the government reneges on its announced price of conventional seeds. Thus for $\forall D \in \left[\tilde{D}_d, \bar{D}_d\right]$ the monopolist charges $p_g\left(D, \tilde{P}_t\right) = \frac{D(1-\alpha)}{s} + \frac{p_x\delta}{s} + \tilde{p}_t$. 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

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

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 conventional seeds, V_d,

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

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

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

Note that $\frac{\left(p_t^e + z\right)}{2} < \left(p_t^e + z\right)$ if $p_t^e > z$ and $\frac{\left(p_t^e + z\right)}{2} > \left(p_t^e + z\right)$ if $p_t^e < z$. In either of these cases, the optimal strategy is to price conventional seeds closer to the associated marginal cost, z. Thus, under rational expectation, $\tilde{p} = p_t^e = \frac{\left(p_t^e + z\right)}{2} \Rightarrow p_t^e = z$ .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 conventional seeds is greater when the monopolist practices perfect discrimination as compared to when the monopolist prices uniformly, since

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

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

4 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 in both information regimes (uniform pricing and perfect price discrimination) the optimal form of intervention for the government wishing to increase GM coverage and maximize domestic welfare is to subsidize the price of conventional seeds. This counter-intuitive result follows from recognizing that GM and conventional seeds are (imperfect) substitutes. Hence, lowering the price of conventional seeds forces the monopolist to reduce the price of GM seeds in order to preserve market share. The optimal size of the conventional seed subsidy depends systematically on the (i) marginal cost of GM and conventional seeds, (ii) price of chemical pesticides, (iii) degree to which GM seeds increase productivity, (iv) range of pest pressure among farmers, and (v) intensity of seed usage (GM and conventional).

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 conventional 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 conventional seeds is higher irrespective of whether the monopolist practices uniform or discriminatory pricing, as compared to the situation where conventional 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.

Appendix

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

The monopolist's profit maximization problem is given by

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

Therefore,

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

Since

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

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

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

which upon simplification yields

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

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

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

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

Therefore,

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

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

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

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

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

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

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

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

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

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

The first order condition is given by

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

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

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

Figure 1: Willingness to Pay for GM

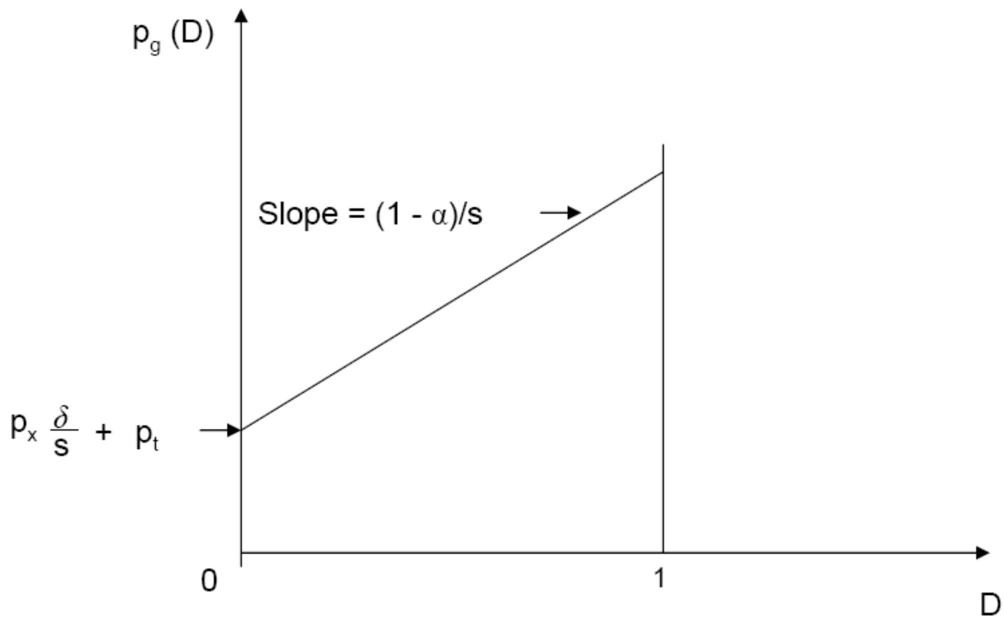


Figure 2: Uniform Pricing, Credible Government

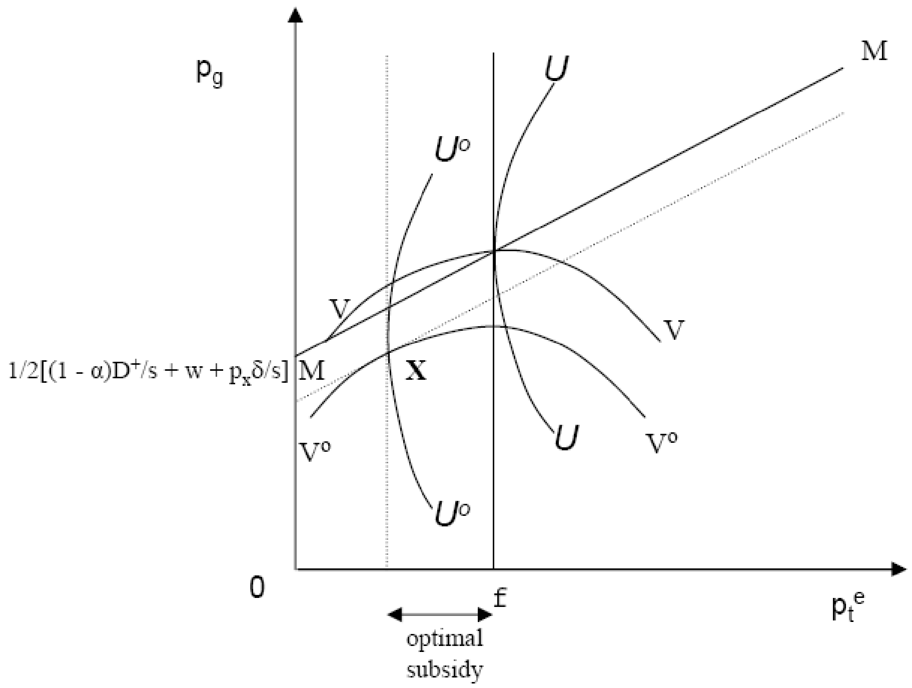


Figure 3: Uniform Pricing, Non-Credible Government

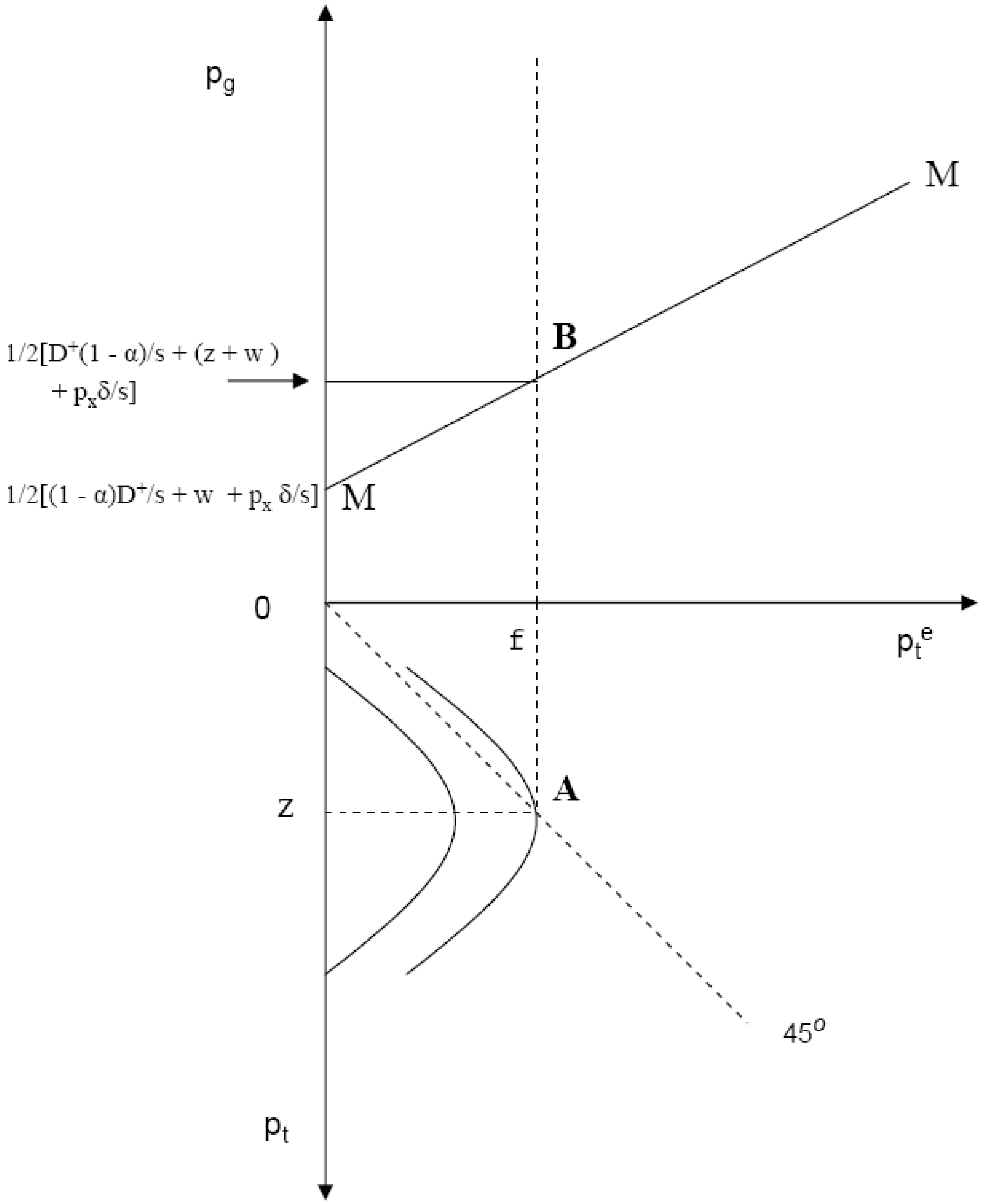
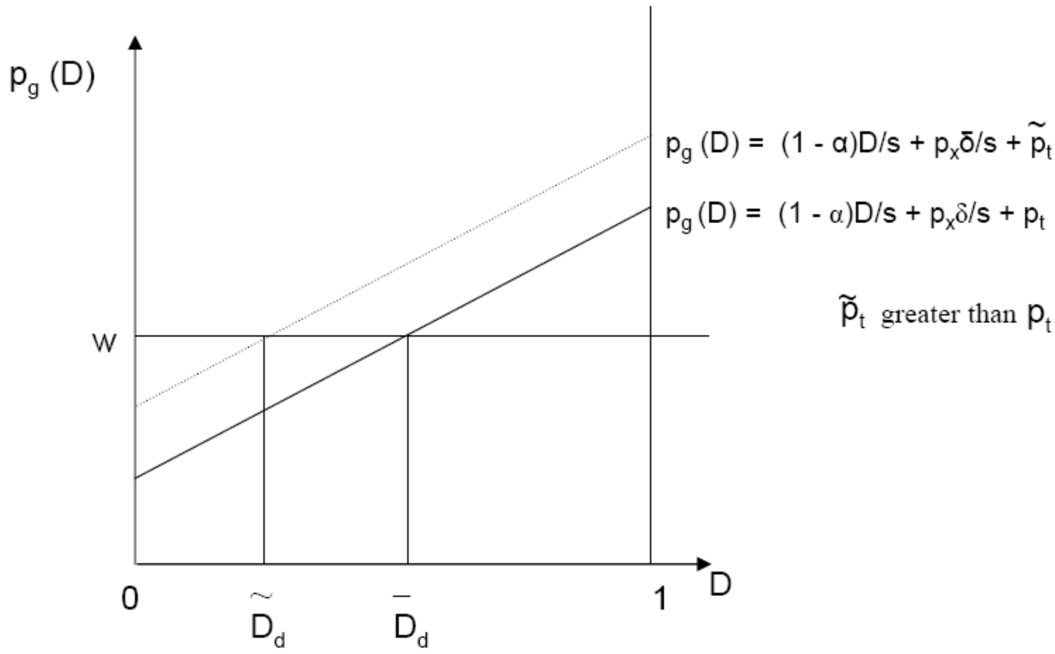


Figure 4: Producers' Self-Selection Perfect Discrimination, Non-Credible Government



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