Incentives to Reduce Crop Trait Durability

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To reduce the competition from farmers who self-produce seed, an inbred line seed producer can switch to nondurable hybrid seed. In a two-period framework, we first investigate the impact of crop durability on self-production, pricing and switching decisions. Second, we study how the introduction of a fee paid by self-producing farmers affects those decisions. We find that the monopolist may produce technologically dominated hybrid seed in order to extract more surplus from farmers. Further, the introduction of a self-production fee improves efficiency.

Keywords: durable good, innovation, license fees, Plant Breeder's Rights.

Incentives to reduce crop trait durability

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In Europe and North America, property rights in the seed sector are based on the Plant Breeder's Rights (PBRs), which grant the plant breeder exclusive rights to a new variety of seed. However, PBRs also allow farmers to use the harvest of one production cycle to self-produce seed for the next. A farmer who buys seed with valuable genetic traits (e.g., productivity, resistance to pests, fitness to a specific climate) has the opportunity to produce crops with the same traits during the next production cycle. Therefore, by self-producing, farmers directly compete with seed dealers. In this sense, crop traits can be considered as durable goods.

In practice, two types of mechanisms can moderate the competition from farmers. The first mechanism is based on technology. To avoid competition from farmers who self-produce, seed dealers can reduce the durability of crop traits. If the quality of the trait decreases dramatically from one generation to the next, self-production becomes economically uninteresting. This can be achieved by developing hybrid seed (as opposed to inbred line seed or "variety").[1] This strategy has been followed for corn since the 1950's, sunflowers during the 1970's, and more recently, for canola and wheat. Table 1 exhibits the importance of self-produced seed and hybrid seed for major crops in France. Although hybrid seeds dominate the markets for corn and sunflowers, the picture is more contrasted for canola, wheat and barley. Hybrid canola has been developed since the 1990's, but it represents only one-third of the market. Most of the seed companies have research programs on both types of seed and regularly introduce new hybrid and inbred line canola. Hybrid wheat has been developed and sold in France during the last 10 years and now represents 100,000 ha.[2,3] For barley, although inbred line seeds still dominate the market, hybrid technology is also available.[4] From a technological viewpoint, developing hybrids for self-pollinated crops (barley and wheat) is feasible, but entails higher production costs. Yet research in genetics with recent advances in biotechnology can lead to more efficient hybridization techniques[5] or to alternative techniques; e.g., Genetic Use Restriction Technology makes harvested seeds sterile (Goeschl and Swanson 2003).

The second mechanism is institutional and relies on intellectual property rights (IPRs) in the seed sector. In Europe, the E.U. directive 2100/94 (article 14) indicates that a farmer who self-produces seed should pay a license fee. This directive has been applied in France for wheat since 2001, and leads self-producing farmers to pay 4-5 Euros per ha.[6] A large portion of the collected fees is assigned to the innovator who created the seed varieties.[7]

Therefore, although seed producers cannot legally prevent self-production, they can technologically discourage it by selling nondurable seed. In this context, we analyze the pricing strategies of an inbred line monopolist when farmers can self-produce, and her decision to reduce crop durability by switching to hybrid seed. We also investigate the impact of the introduction of a self-producing fee and its welfare implication.

In our setting, farmers can only self-produce inbred line seed (with heterogenous self-production costs). We assume that the seed is produced by a monopolist who is more efficient in producing seed than farmers. Self-production is thus sub-optimal, but it appears to compete with powerful (monopolistic) seed dealers. We also assume that hybrid seeds are more costly to produce (by the seed producer), but that once planted they are more productive (for farmers) than inbred line seed. Therefore, we impose no *a priori* technological domination of one type of seed over the other, as this will become a main parameter of our analysis.

We first consider the case of a monopolist who only produces inbred line seed. In this context, we show that the monopolist sells seed as a durable good to farmers who inefficiently self-produce. The introduction of a fee increases efficiency by making self-production less attractive. It therefore renders the nondurable good strategy more profitable, and assigns efficiency gains to the monopolist. Second, if the monopolist can produce hybrid seed instead of inbred line seed, we show that she has an incentive to introduce technologically dominated hybrid seed (i.e., hybrid seed is less productive than the inbred) in order to extract more surplus from farmers. The monopolist, indeed, decides to inefficiently shorten the durability of the crop. The introduction of a self-production fee reduces the incentive to switch to inefficient hybrid seed.

Finally, two remarks should be made concerning our modeling framework. First, our focus is to study pricing strategies in the seed industry in the presence of IPRs. Seed companies generally invest more than 10% of their sales in research, driven by the prospect of expected market power provided by innovation. This is why we assume that the seed is supplied by a monopoly rather than a competitive industry, even if a competitive industry would, *ex post*, be more efficient. Second, we adopt a very simplified representation of the decision to switch from inbred line seed to hybrid seed. In reality, it is a long-term decision, as developing hybrid seed requires the launching of different plant breeding programs and the development of different production techniques. There is a complex transition process that is not accounted for here. However, a seed company will commit to such a transition only if she anticipates higher profits in the future. Hence, our analysis is restricted to a necessary condition that the seed producer decides to switch from an inbred line to hybrid seed.

Related literature

Our contribution is related to the literature on durable goods. The Coase conjecture states that monopoly pricing of durable goods leads to exhaustion of the monopoly rent. This is due to the fact that the monopolist cannot commit to not reducing prices in the future. She would like to commit to high prices (e.g., the monopoly price) but later is tempted to cut prices to attract the residual demand. Expecting this behavior, consumers will buy at marginal cost at most (see Coase 1972; Bulow 1982; Gul, Sonnenschein and Wilson 1986; Waldman 2003). Here the problem is different, because the good can be sold during each period as a nondurable good to be used by farmers for only one period. This is indeed what the monopolist would like to do: sell seed in each period at the per-period monopoly price. However, PBRs introduce an outside option to farmers to produce their own seed. Future seed prices are thus bounded by self-production costs. When the costs are low enough, the monopolist prefers to sell seed as a durable good (used during several periods) at a price equal to the multi-period benefit, net of the farmer's self-production cost. Doing so, she can indirectly appropriate part of the revenue from self-produced seed.

In a different context, Liebowitz (1985) provides evidence of the indirect appropriation of revenue from consumers who do not directly purchase journals, but rather copy them. Allowing for product reproduction entails a loss of property rights. It is similar to the loss due to seed self-production, with the difference that the user of the "copied" seed is the farmer who purchased it, and seeds are nondurable when not "copied." Related, Takeyama (1997) shows that copying is harmful for the monopolist if she can commit on future prices (like in the present article), but might help her to mitigate Coase's commitment problem.

The self-production cost is the price paid by users for extending the benefit of the durable good to the next period. It is, thus, similar to maintenance expenditures for deteriorated durable goods. Schmalensee (1974) shows that consumers tend to over-maintain their used units of goods when maintenance is priced at marginal cost (e.g., due to perfect competition in the maintenance industry), while new units are priced above marginal cost. Similarly here, farmers inefficiently self-produce because the monopolist sets the price above the self-production cost. A competitive seed market would restore efficiency by pricing seed below self-production costs. One way to avoid self-production inefficiency (as well as the time inconsistency problem pointed out by Coase 1972; Bulow 1982; and others) is to monopolize the maintenance market (Morita and Waldman 2004). In our case this means to monopolize seed production, but this violates PBRs.

The literature on product durability was influenced by Swan's independence result (Swan 1970; 1971) that states that a monopolist provides socially optimal durability. It requires that the good does not depreciate over time. In our framework, an interpretation of the relative inefficiency of self-production is a loss of return due to gene contamination or lower germination. In this case, the return provided by the seed depreciates when self-produced. Waldman (1996a) shows that with quality deterioration and heterogeneous consumers, durability is underprovided. Hendel and Lizzeri (1999) generalize and extend this result when there exists a secondary market for used goods. Similarly here, the seed dealer introduces less efficient nondurable hybrid seed, although perfect competition would restore efficiency.

Selling hybrid instead of durable inbred line seed is somewhat like leasing the durable good for one period instead of selling it. Waldman (1997) argues that a lease-only policy eliminates the market for the used good, which increases the producer's market power. In the case of seed, PBRs forbid the sale of self-produced seed and, thus, prevent the emergence of a secondary seed market. In our model, allowing for such a secondary market would render self-production more attractive, because self-production would be assigned to the more efficient farmers. It would reduce further the seed dealer's market power and, hence, increase the incentive to reduce crop trait durability.

Shortening crop trait durability is similar to the planned obsolescence of durable goods (Bulow 1986; Waldman 1996b). Bulow (1986) formalizes the monopoly's incentive to uneconomically shorten the durability of goods in a two-period model. Our framework is different in two ways. First, we deal with a good that leaves the option for consumers to make it durable at a cost. The monopolist wants to introduce an uneconomical good that does not provide this option. Second, consumers have heterogeneous surplus captured by seed production costs when they have the option to make the good durable. As a consequence, for some values of the parameters, the monopolist chooses to produce both types of seed to differentiate consumers.

Our contribution is related to the literature on the impact of IPRs within the seed industry. Burton *et al.* (2005) examine the property rights protection of genetically modified

(GM) crops in a two-period model. They compare sterile GM seeds with short-term and long-term contracts between the seed producer and farmers as strategies to protect IPRs. Their focus is mainly on enforcement and monitoring problems with long-term contracts that can be avoided with sterile GM seeds. Perrin and Fulginiti (2004) investigate the pricing of different types of seeds under different IPR regimes in a model close to that of Bulow (1982).

Finally, several contributions analyze the impact of IPRs within the seed industry on the incentives to enhance innovation. Their focus is on the standard trade-off between *ex ante* (stronger IPRs create more incentive to invest in research) versus *ex post* (deadweight loss due to market power) efficiency, and the difference between inbred line and hybrid seed is captured through different levels of a property rights parameter (Alston and Venner 2002; Lence *et al.* 2005).[8] Our analysis complements the above contributions in that the choice of the type of seed is endogenous, while the preliminary research stage is exogenous. Further, we study the impact of a fee paid by farmers who self-produce.[9]

The model

We consider a two-period model in which a seed producer faces a continuum of farmers of mass 1. The discount factor is normalized to 1. Each farmer buys zero or one units of seed. The monopolist produces and sells inbred line seeds (L) at a marginal cost 0. As the technology becomes available (at no cost), she may also produce and sell hybrid seeds (H) at a higher marginal cost $c > 0$. The gross payoff to the farmer from using inbred line seed or hybrid seed is Π_j (with $j = H, L$) and is identical for all farmers. We suppose that $\Pi_H > \Pi_L$, so that hybrid seeds generate a higher payoff but are more costly to produce. Yet we assume that it is worthwhile to use hybrids, i.e., $\Pi_H - c > 0$.

Not only do the two types of seed have different costs and profits, they also differ in their durability. Unlike hybrid seed, the inbred line harvest can be saved and used to produce seed for the next period's production. If a farmer buys inbred line seed at the beginning of the first period, he can produce his own second-period seeds at a cost θ that includes the cost of saving part of the harvest. Importantly, farmers differ in their self-production costs θ, where θ is uniformly distributed between 0 and $\overline{\theta}$. The density is $f(\theta)$ and the cumulative function is $F(\theta)$ on $[0, \overline{\theta}]$, where $F(0) = 0$ and $F(\overline{\theta}) = 1$. Thus, $F(\theta)$ is the fraction of farmers with a cost less than θ.

Two main arguments justify that the cost of producing inbred line seed is lower for the seed producer than for self-producing farmers. First, it is generally established that there are economies of scale at some stages of the production process (e.g., screening, seed dressing). Seed producers benefit more from these economies of scale because they produce seed for the whole market. Second, the yield obtained by self-production is slightly lower than that obtained from seed bought from seed producers. Here, we assume that self-production does not affect the profit Π_L. Hence, self-production costs should be interpreted in a broader sense and should include the cost of the yield loss.[10]

In our setting, self-production by farmers is socially inefficient because the inbred line seed producer's marginal cost is equal to zero. Therefore, at the first-best, all seeds are produced by producers. Moreover, only one type of seed is produced at the first-best.

Indeed, if a social planner can choose prices and decide whether to switch or not, he sets the price equal to marginal cost, i.e., zero for inbred line seed and c for hybrid seed. The two-period welfare is then $2\Pi_L$ if inbred line seeds are produced and $2(\Pi_H - c)$ if hybrid seeds are produced. Hence, the social planner switches to hybrid seed if $\Pi_H - c \geq \Pi_L$, or equivalently, $\Pi_H - \Pi_L \equiv \Delta\Pi \geq c$; i.e., the harvest gain compensates for the incremental cost of producing hybrid seeds.

Yet the first-best outcome could be achieved with perfect competition in the inbred line seed market and with a monopoly setting in the hybrid seed market. The logic here is straightforward. Inbred line seed producers set their price at marginal cost zero (as in the case of price setting by a social planner). Farmers buy during each period, as it would be (weakly) more costly to self-produce ($\theta \geq 0$). In order to enter the market, a hybrid seed producer has to set his price at $\Delta\Pi$ (such that $\Pi_H - p = \Pi_L$), or possibly just below. If $\Delta\Pi < c$, the hybrid seed producer does not enter and only inbred line seeds are produced. On the other hand, if $\Delta\Pi \geq c$, the hybrid seed producer enters and only hybrid seeds are produced. In this latter case, all of the farmers buy the hybrid seeds, and the (maximized) total surplus is shared between the farmers and the producer. Furthermore, hybrid seeds are efficiently produced. Therefore, any loss of efficiency in seed pricing or in the reduction of trait durability is due to the exercise of market power in the inbred line seed industry.

Inbred line monopoly

In this section we consider a monopolist who sells only inbred line seed, at prices p_{1L} and p_{2L}, during the first and second periods. The timing of decisions is as follows. In the first period, the monopolist offers a pair of prices $\{p_{1L}, p_{2L}\}$. The farmers observe these prices, each decides whether or not to buy the seed at price p_{1L}, and then each decides whether or not to self-produce for the second period. In the second period, those who did not save part of the harvest have to decide whether to buy the seed at price p_{2L}.

Note that such timing requires the monopolist to be able to commit to the second-period price before the farmers decide to self-produce. In reality, it means that the farmers can save part of their harvest and decide, just before sowing, whether to use it as (self-produced) seed or to sell it on the spot market. The alternative "non-commitment" case will be addressed as an extension of our model in a later section.

We first derive the equilibrium, and second, we analyze the impact of the introduction of a self-production fee.

Equilibrium without a self-production fee

To fully understand the monopoly's pricing strategy, we first consider what happens in the case of homogeneous farmers, i.e., when they all have the same cost θ. While committing on a price schedule, the monopolist can adopt two different strategies. Either she sells the seed in the first period to be used for the two periods, and therefore sells nothing in the second period (the "durable good" strategy) or, instead, she sells the seed during the two periods (the "nondurable good" strategy). In the case of the durable good strategy, the first-period price is equal to the two-period seed value,[11] namely $p_{1L} = 2\Pi_L - \theta$. The monopolist gets the entire surplus, whereas farmers get nothing. However, since seeds are inefficiently self-produced by farmers, the total surplus can be increased if the monopolist sells seeds in the second period. In this case (the nondurable good strategy), in the second period, the monopolist faces competition from farmers that forces the second-period price to be equal to the farmers' costs, i.e., $p_{2L} = \theta$ (if higher, farmers produce their own seed). In the first period, the monopolist exerts her full market power by selling the one-period seed at its one-period value, i.e., $p_{1L} = \Pi_L$. The total surplus is maximized, but it is shared between the monopolist, who gets $(\Pi_L + \theta)$, and the farmers, who get $(\Pi_L - \theta)$. The monopolist has to choose between an inefficient outcome (durable good strategy), where she gets all of the surplus, and an efficient one (nondurable good strategy), where she shares the surplus. She adopts the durable good strategy and only sells in the first period (respectively, the nondurable good strategy and sells during the two periods), when $\theta \leq \Pi_L/2$ (respectively, $\theta > \Pi_L/2$).

We now turn to what happens when farmers are heterogeneous in their self-production cost θ. In this case, the monopolist faces a similar trade-off: either she offers the seed as a durable good to some farmers (those with lowest self-production costs) or she offers the seed during the two periods as a nondurable good to all farmers.

First, a durable good monopolist sets her prices so as to sell to the farmers who self-produce seed in the first period, and to the others (if any) only in the second period. The latter farmers are charged their reservation price in the second period $p_{2L} = \Pi_L$, so that their payoff is nil. A farmer whose self-production cost is θ buys the seed as a durable good (in the first period) if $\Pi_L - p_{1L} + \Pi_L - \theta \geq 0$. Hence, there exists a farmer who is indifferent between buying or not, i.e., whose self-production cost is $\widetilde{\theta} = 2\Pi_L - p_{1L}$ as long as $\widetilde{\theta} \leq \bar{\theta}$. Farmers with self-production costs higher than $\widetilde{\theta}$ buy seed only in the second period. The monopoly's program is thus

$$(1) \qquad \begin{cases} \underset{p_{1L}}{Max} \left[p_{1L} \int_0^{\widetilde{\theta}} f(\theta) d\theta + \Pi_L \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta) d\theta \right] \\ \text{subject to } \widetilde{\theta} = \min\{2\Pi_L - p_{1L}, \bar{\theta}\}. \end{cases}$$

If $\bar{\theta} > \Pi_L/2$, there exists an interior solution: in the first period, the monopolist sells to self-producing farmers (those with $\theta \leq \Pi_L/2$) at price $p_{1L} = 3\Pi_L/2$, and in the second period, she sells to the rest of the farmers at price $p_{2L} = \Pi_L$. If $\bar{\theta} \leq \Pi_L/2$, the solution is a corner solution: in the first period the monopolist sells to all of the farmers at price $p_{1L} = 2\Pi_L - \bar{\theta}$, and to none of them in the second period. Hereafter, we restrict attention to the second case and, therefore, assume $\bar{\theta} \leq \Pi_L/2$.[12]

Second, a nondurable good monopolist sells seeds during the two periods. In the second period, only farmers with a self-production cost higher than the second-period price p_{2L} buy the seed. In this setting, two constraints must be satisfied: the monopolist must make sure that farmers buy in the first period ($\Pi_L - p_{1L} \geq 0$) and that some farmers buy in the second period ($\Pi_L - p_{2L} \geq \Pi_L - \theta$). Hence, the nondurable good monopoly program is[13]

$$(2) \qquad \begin{cases} \underset{p_{1L}, p_{2L}}{Max} \left[p_{1L} + p_{2L} \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta) d\theta \right] \\ \text{subject to} \quad \Pi_L - p_{1L} \geq 0, \\ \qquad\qquad\quad \widetilde{\theta} = \min\{p_{2L}, \bar{\theta}\}. \end{cases}$$

The equilibrium prices, monopoly payoff and farmers' surplus are summarized in table 2.

With a durable good strategy, all of the farmers buy seed in the first period and self-produce for the second period. With a nondurable good strategy, all of the farmers buy seed in the first period and half of them buy seed in the second period (the other half self-produce).

The total surplus is higher (or, equivalently, the loss of welfare is lower) with a non-durable good strategy than with a durable good strategy, because a smaller proportion of farmers self-produce. The farmers' surplus is also higher with a nondurable strategy, because the first-period price is lower and, in addition, farmers with high self-production costs ($\theta > \bar{\theta}/2$) buy seed in the second period instead of self-producing. However, the monopoly payoff is higher when seed is sold as a durable good.[14] Hence, appropriability motives drive the monopolist to choose the pricing strategy that leads to the lower total surplus. Indeed, the durable good strategy dominates the nondurable good strategy.

Equilibrium with a self-production fee

With reference to E.U. directive 2100/94, we consider here the case where farmers who self-produce must pay an exogenous fee τ to the monopolist, where $0 < \tau \leq \Pi_L$.

If the monopolist chooses the durable good strategy, the imposition of a fee does not change our findings. Indeed, the monopolist simply accounts for it in her program. The price paid by farmers, $p_{1L} + \tau$, is equal to $2\Pi_L - \bar{\theta}$ and, thus, her profit is unchanged, $2\Pi_L - \bar{\theta}$.

However, things are different when the monopolist chooses the nondurable good strategy. Indeed, because the imposition of a fee makes self-production more costly, some farmers no longer self-produce and, therefore, the nondurable good strategy becomes more attractive to the monopolist. The monopolist's program is now

$$
(3) \qquad \begin{cases} \underset{p_{1L},p_{2L}}{Max} \left[p_{1L} + \tau \int_0^{\widetilde{\theta}} f(\theta)d\theta + p_{2L} \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta)d\theta \right] \\ \text{subject to} \quad \Pi_L - p_{1L} \geq 0, \\ \qquad\qquad\quad \widetilde{\theta} = \min\{p_{2L} - \tau, \bar{\theta}\}, \\ \qquad\qquad\quad p_{2L} \leq \Pi_L. \end{cases}
$$

In this program, the fee does not affect the first-period monopoly payoff, but it does affect the second-period payoff, for two reasons. First, consider farmers who self-produce. Because of the introduction of a fee, part of their second-period surplus is transferred to the monopolist. The benefit from self-producing decreases, but it can still be positive for the most efficient farmers. Second, consider farmers who buy seed during the two periods. Their propensity to pay for seed depends on the surplus they can alternatively earn by self-producing. This alternative being less profitable, the monopolist can charge a higher price to these farmers and extract more surplus from them. The introduction of a fee leads to an upward shift of the second-period seed demand function.

The equilibrium prices, profit and surplus are summarized in table 3. If τ is low enough, the upward shift of the demand function leads the monopolist to increase the second-period price by τ. Because of the fee, the monopolist earns τ more from each farmer: the first half, which self-produces, pays this fee, and the second half, which buys in the second period, pays a higher price. The welfare loss does not depend on τ, because it is only a transfer from the farmers to the monopolist, the proportion of self-producing farmers being constant. When the fee becomes higher (greater than $\Pi_L - \bar{\theta}/2$), the second-period price hits the constraint $p_{2L} < \Pi_L$. As the fee increases, it becomes more profitable for self-producing farmers to buy the seed instead. The monopolist extracts all of the surplus from the farmers who buy during the two periods (those with $\theta > \Pi_L - \tau$) and the proportion of these farmers increases with the fee. The welfare loss decreases with τ as the proportion of self-producing farmers decreases. At the extreme, when $\tau = \Pi_L$ no farmer self-produces and the monopolist extracts all of the surplus. Finally, with a nondurable good strategy the fee increases the monopoly profit, decreases the farmers' surplus, and does not decrease efficiency. The monopoly profit is higher than the (possible) increase in the total surplus because it also benefits from the decrease in the farmers' surplus.

Insert figure 1

Without a self-production fee, we have seen that the durable good strategy dominates the nondurable good strategy. The introduction of a fee does not affect the durable good monopoly payoff, but increases the nondurable good monopoly payoff (see figure 1). Therefore, for low enough values of the fee ($\tau < \Pi_L - 5/4\bar{\theta}$), the durable good strategy still dominates, as the nondurable good monopoly payoff is still lower than the durable good monopoly payoff. However, as the fee becomes higher, the monopoly payoff becomes greater with a nondurable good strategy than with a durable good strategy.

We sum up the findings of the previous analysis in the following proposition.

Proposition 1 *By reducing self-production, a self-production fee $\tau > \Pi_L - 5\bar{\theta}/4$ increases both the efficiency and the monopolist profit. When $\tau = \Pi_L$, efficiency is restored and the monopolist gets all of the surplus.*

Introduction of hybrid seed

We now consider that hybrid seed becomes available exclusively to the monopolist at constant marginal cost $c > 0$. Let p_{tj} denote the price charged in period $t = 1, 2$ for seed $j = H, L$ (if sold). When given the choice between the two types of seeds, farmers must decide which to buy. If they buy hybrid seed in the first period, they cannot self-produce and, therefore, in the second period they have to buy the available seed.

In this setting, we investigate under what circumstances the monopolist decides to switch to hybrid production. We consider the case in which the monopolist can only produce one type of seed (hybrid or inbred line), for technological, legal and/or marketing reasons. The case in which the monopolist sells both seeds is analyzed as an extension in the following section, as it leads to results of the same flavor, at a cost of more complex computations.

Formally, we add an *ex ante* decision stage, in which the monopolist can switch to hybrid or keep producing inbred line seed at the beginning of the first period. If inbred line seed is produced, the timing of events proceeds as described before. However, if hybrid seed is produced, farmers cannot self-produce, and they only have to decide whether to buy or not during each period.

If the monopolist switches to hybrid seed in the first period, she behaves as a nondurable good monopolist and, therefore, sets the monopoly price in each period: $p_{1H} = p_{2H} = \Pi_H$. None of the farmers can use their own seed for the next period, and they all buy seeds at their valuation, Π_H. The monopoly two-period payoff is $2(\Pi_H - c)$ and farmers get a null surplus.

If the monopolist keeps producing inbred line seed, we know from the previous section that she adopts the durable good strategy. Her two-period payoff is $2\Pi_L - \bar{\theta}$ and the farmers' surplus is $\bar{\theta}/2$. Therefore, the monopolist switches to hybrid seed in the first period[15] if $c \leq \Delta\Pi + \bar{\theta}/2$. However, from a social viewpoint, hybrids should be produced only if $c < \Delta\Pi + \bar{\theta}/4$. Further, hybrid seed is technologically dominated whenever $c > \Delta\Pi$.

Depending on the value of c, four areas can be defined (see Figure 2 for $\tau = 0$). (1) If $c < \Delta\Pi$, the monopolist switches to hybrid seed, which is the most efficient technology (first-best choice). The switch avoids inefficiency due to self-production, and further, it is socially efficient. (2) If $c \in [\Delta\Pi, \Delta\Pi + \bar{\theta}/4]$, the monopolist switches to dominated hybrid seed, even though the switch is efficient. The switch occurs because by avoiding self-production, hybrid technology allows the monopolist to extract all of the surplus. (3) If $c \in [\Delta\Pi + \bar{\theta}/4, \Delta\Pi + \bar{\theta}/2]$, the dominated hybrid seed is still produced, but the switch is now socially inefficient. From society's viewpoint, the monopolist should keep producing inbred line seed, as the inefficiency loss due to self-production is smaller than the inefficiency loss due to the production of dominated hybrid seed. (4) If $c > \Delta\Pi + \bar{\theta}/2$, the monopolist keeps producing inbred line seed, which is an efficient choice.

Insert figure 2

We sum up this result in the following proposition.

Proposition 2 *If $c \in [\Delta\Pi, \Delta\Pi + \bar{\theta}/2]$, the monopolist switches to technologically dominated hybrid seed. This switch is socially efficient as long as $c \leq \Delta\Pi + \bar{\theta}/4$.*

We now investigate whether the introduction of a self-production fee provides the monopolist with incentives to switch to hybrid seed when it is efficient to do so. Figure 2 represents how the four areas described earlier are affected by the fee.

For $\tau \in (0, \Pi_L - 5\bar{\theta}/4]$, we have already shown that a fee has no effect on the monopoly payoff (see figure 1). Therefore, a small fee does not affect incentives to switch. For $\tau \in [\Pi_L - 5\bar{\theta}/4, \Pi_L]$, the inbred line monopolist chooses the nondurable good strategy, with different pricing strategies depending on the fee (see Table 3). Hence, for $\tau \in [\Pi_L - 5\bar{\theta}/4, \Pi_L - \bar{\theta}/2]$ (respectively, $\tau \in [\Pi_L - \bar{\theta}/2, \Pi_L]$), the monopolist switches to hybrid when $c \leq \Delta\Pi - \bar{\theta}/8 + (\Pi_L - \tau)/2$ (respectively, $c \leq \Delta\Pi + (\Pi_L - \tau)^2/2\bar{\theta}$), which is efficient only for $c \leq \Delta\Pi + \bar{\theta}/16$ (respectively, $c \leq \Delta\Pi + (\Pi_L - \tau)^2/4\bar{\theta}$). Figure 2 represents the impact of the fee on the four different areas presented before. The "inefficiency area" (area 3), in which the monopolist switches although it is efficient to keep producing inbred line seed, first becomes relatively bigger and then shrinks as τ increases. This is because a higher fee increases the payoff of the inbred line seed monopoly and, thus, makes the switch to dominated hybrid seed less attractive. Yet this inefficiency area exists as long as $\tau < \Pi_L$, meaning that a self-production fee does not always provide incentives to efficiently switch. The monopolist switches at the efficient threshold level only for the extreme value $\tau = \Pi_L$. This corresponds to the case where there is no efficiency loss due to self-production and the monopolist gets all of the surplus from inbred line seed production. We summarize these findings in the following proposition.

Proposition 3 *The introduction of a self-production fee makes the monopolist switch inefficiently to hybrid seeds less often. She always switches efficiently when the fee allows her to capture all of the surplus with inbred line seeds, i.e.,* $\tau = \Pi_L$.

Extensions

In this section we provide three extensions of the model and show that our main findings (provided in propositions 1 to 3) are still qualitatively valid. More precisely, the general properties are identical, but the threshold level on the parameters may be different. For the sake of simplicity, we only present the intuitions of our findings and we leave out the details of the calculation.[16]

The first extension is concerned with the analysis of the non-commitment case on future prices. The second deals with the possibility for the monopolist to discriminate among farmers who bought the seed in the first period and those who did not. And lastly, we explore the case in which the monopolist can produce both hybrid and inbred line seeds at the same time.

Non-commitment on future prices

In the inbred line seed monopoly analysis, farmers make their self-producing decision *after* observing the second-period price. Some farmers prefer not to self-produce if the second-period price is lower than $\bar{\theta}$. However, once this decision is made, the farmers that do not self-produce become captive and the monopolist may then be tempted to raise the second-period price. Here we analyze this alternative case, where the monopolist cannot commit not to raise her second-period price.

The longer the period between harvesting and sowing (for the next season), the more accurate it is to consider this non-commitment case. For instance, let us consider the case of wheat in France. The harvest occurs in summer and the sowing period is either during the fall (for winter wheat) or spring (for spring wheat). In the first case, the time lag between the harvest and the planting is short; thus, farmers can stockpile part of their harvest and choose whether or not to use it for planting after observing seed prices. This corresponds to the commitment case. In the second case, farmers have to stockpile for a longer period and this alternative is costly, even if they can sell their stock of seeds on the spot market.

In the non-commitment case, the monopolist makes her second-period pricing decision after the farmers' self-production decision. If a farmer decides not to self-produce, he becomes captive and will still buy the seed at any price lower or equal to the seed value, Π_L. The monopolist sets her second-period price at Π_L. Expecting that price, none of the farmers buy the second-period seed, as they are better off if they self-produce.[17] Moving now to the first period, knowing that all of the farmers will self-produce, the first-period optimal price is then $2\Pi_L - \bar{\theta}$. This pricing equilibrium is the same as the one obtained with a durable good strategy in the commitment case, and so are the monopoly payoff and farmers' surplus (c.f., table 2).

The introduction of a (high enough) fee allows the farmers with the highest self-production costs to earn more in the second period if they buy seed at Π_L than if they self-produce. If $\tau > \Pi_L - \bar{\theta}$, the monopolist is better off if she switches to the nondurable good pricing $p_{1L} = p_{2L} = \Pi_L$. Note that this pricing strategy is also obtained in the case with commitment (c.f., table 3).

The equilibria in the non-commitment case are identical to ones we obtained in the commitment case. Not surprisingly, the findings obtained with commitment are still valid in the non-commitment case: a monopolist who cannot commit on future prices adopts a durable good strategy. She sells to all of the farmers in the first period and to none of them in the second period. The introduction of a self-production fee increases efficiency by reducing self-production.

Inbred line monopoly pricing and discrimination

In the previous analysis, implicitly, no price discrimination among farmers was allowed. Indeed, we have not considered the case where the monopolist can sell inbred line seed in the second period at different prices depending on whether farmers bought seed in the first period.[18]

It is easy to show that by discriminating, the monopolist can extract all of the surplus if she commits on future prices. Indeed, by pricing at $2\Pi_L$ in the first period, with the promise of providing free seed in the second period, she sells to every farmer at the farmers' surplus $2\Pi_L$. However, in the second period, she has an incentive not to keep her promise and to sell the seed at a positive price. Expecting this behavior, no farmers (with strictly positive self-production costs) buy at $2\Pi_L$. Therefore, we investigate monopoly pricing with discrimination but without commitment on future prices. In addition to the per period prices p_{1L} and p_{2L}, we introduce a special second-period price $\hat{p}_{2L}$ for farmers who purchased seed in the first period. We solve by backwards induction.

In the second period, farmers who did not buy the seed in the first period represent captive demand and, thus, the monopolist can set the price $p_{2L} = \Pi_L$. Those who did buy seed in the first period are those with a low θ. Indeed, if it is optimal for a farmer θ' to buy seed in the first period, it is optimal for every farmer $\theta < \theta'$. We denote $\tilde{\theta}$ as the farmer who is indifferent between buying during both periods and buying only in the second period. Among farmers who buy in the first period, those with the highest self production cost ($\theta > \hat{p}_{2L}$) prefer to buy seed in the second period. In the second period, the monopolist maximizes $\int_{\hat{p}_{2L}}^{\tilde{\theta}} \hat{p}_{2L} f(\theta) d\theta$ with respect to $\hat{p}_{2L}$. The first-order condition yields $\hat{p}_{2L} = \tilde{\theta}/2$.

Among farmers who bought seed in the first period, those with self-production cost θ higher than $\hat{p}_{2L}$ also buy seed in the second period. Therefore, farmers with self-production costs $\theta \in [\tilde{\theta}/2, \tilde{\theta}]$ buy seed in each period. They obtain the same surplus $2\Pi_L - p_{1L} - \tilde{\theta}/2$. This surplus is nil because, by definition, the farmer $\tilde{\theta}$ is indifferent between buying during both periods and buying only in the second period, in which case he gets $\Pi_L - p_{2L} = 0$. Hence, $p_{1L} = 2\Pi_L - \tilde{\theta}/2$. We assume that in the case of indifference, farmers prefer to buy in both periods, which implies that all of the farmers who do not self-produce buy seed in each period. Therefore, $\tilde{\theta} = \bar{\theta}$, which implies $\hat{p}_{2L} = \bar{\theta}/2$ and $p_{1L} = 2\Pi_L - \bar{\theta}/2$.

A discriminating monopolist sells seed to all of the farmers in the first period at a higher price than without discrimination (c.f., table 2, durable good strategy). All of the farmers buy, either because they have low self-production costs (and then self-produce) or expect to buy at price $\hat{p}_{2L} = \bar{\theta}/2$, which is lower than $p_{2L} = \Pi_L$. Half of the farmers self-produce at a cost $\theta \leq \bar{\theta}/2$, and thus obtain a positive surplus $\bar{\theta}/2 - \theta$. The other half, with high self-production costs, buy seed in each period and obtain zero surplus. Hence, price discrimination leads to a reduction of self-production. The monopolist extracts all of the surplus from the latter farmers and only $2\Pi_L - \bar{\theta}/2$ from those who self-produce. She thus obtains strictly more from all of the farmers by discriminating.

The introduction of a self-production fee raises the farmer's self-production outside option. It allows the monopolist to increase the second-period price to $(\bar{\theta}+\tau)/2$. This reduces self-production from farmers with $\theta \leq (\bar{\theta}-\tau)/2$. The first-period price decreases at $2\Pi_L - (\bar{\theta}+\tau)/2$. The royalty fee increases the monopoly payoff. Indeed, in addition to reducing self-production, it also increases the surplus extracted from the farmers who self-produce to $2\Pi_L - \bar{\theta}/2 + \tau/2$. Since fewer farmers self-produce, it also increases efficiency.

By setting different second-period prices for farmers who self-produce and those who do not, a discriminating monopolist increases her payoff by reducing self-production. The introduction of a fee reduces self-production even more, and increases efficiency.

Multi-seed production

We now analyze what happens when the monopolist can sell both types of seeds, in the case of commitment on future prices when there is no price discrimination.[19]

If hybrid seed is more efficient than inbred line seed, i.e., $c < \Delta\Pi$, the monopolist prefers to sell only hybrid seed, because she then extracts all of the surplus, and this surplus is greater with hybrid seed than inbred.

However, if inbred line seed is more efficient than hybrid seed, i.e., $c > \Delta\Pi$, the monopolist can introduce hybrid seed for discriminatory purposes. Recall that when selling only inbred line seed, the monopolist is constrained to set a reasonable price in the first period, as otherwise some farmers would prefer not to buy, and this would reduce the monopoly payoff. The constraint is relaxed in the multi-seed case because, by selling hybrid seed in the first period, the monopolist can earn some payoff from farmers who do not buy inbred line seed.

For the monopolist, the optimal second-period inbred line seed price is Π_L and the optimal first-period hybrid seed price is Π_H. With such prices, any farmer can at least earn no surplus by buying inbred line seed in the first period and hybrid seed in the second period.[20] The alternative for farmers is to buy inbred line seed in the first period and self-produce. Their surplus is then $2\Pi_L - p_{1L} - \theta$. Hence, all of the farmers with $\theta < 2\Pi_L - p_{1L}$ prefer to buy inbred line seed in the first period, and the rest prefer to buy hybrid seed. The monopoly's program is[21]

$$(4) \qquad \begin{cases} \underset{p_{1L}}{Max} \left[p_{1L} \int_0^{\widetilde{\theta}} f(\theta) d\theta + (\Pi_H - c + \Pi_L) \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta) d\theta \right] \\ \text{subject to } \widetilde{\theta} = \min\{2\Pi_L - p_{1L}, \bar{\theta}\}. \end{cases}$$

We do not describe the details of the solution and we only compare this multi-seed strategy to the mono-seed strategy analyzed before. Recall that when only inbred seed is sold, the monopolist adopts a durable good strategy, and then all of the farmers buy seed in the first period and self-produce.

We show that the monopoly payoff is higher with a multi-seed strategy only if $c \in [\Delta\Pi, \Delta\Pi + 2\bar{\theta}]$. The adoption of the multi-seed strategy also affects the farmers' surplus, as some farmers switch from buying inbred line seed in the first period and self-producing, to buying hybrid seed in the first period and inbred line seed in the second period. This switch has an ambiguous effect on the surplus. On one hand, there is a loss in the first period because these farmers use a less efficient hybrid seed. On the other hand, there is a gain in the second period because the inbred line seed they use is produced at a lower cost (0 instead of θ). In fact, we show that the multi-seed strategy increases the surplus if $c \leq \Delta\Pi + 2\bar{\theta}/3$.

In summary, when the monopolist has the option to sell both hybrid and inbred line seeds during the same period, she produces both technologically dominated hybrid seed and inbred line seed if $c \in [\Delta\Pi, \Delta\Pi + 2\bar{\theta}]$. This is efficient only when $c \leq \Delta\Pi + 2\bar{\theta}/3$.

A fee on self-produced seed has a similar impact on the incentive to introduce hybrid seed as does the mono-seed monopolist case examined before. In a nutshell, as in the mono-seed case, a low fee has no impact on this decision. However, beyond a threshold, the fee reduces the range of the inefficient introduction of technologically dominated hybrid seed. This range shrinks as the fee increases.

Therefore, a multi-seed monopolist produces both seeds even though hybrid seed is technologically dominated. The introduction of a self-production fee reduces the inefficient introduction of hybrid seed.

Lastly, it is worth mentioning that there are similarities between the multi-seed strategy derived above and the second-period price discrimination analyzed previously. In both cases, the monopolist uses these strategies in order to discriminate between farmers with low self-production costs and those with high self-production costs. The first type of farmer is willing to buy inbred line seed in the first period at a higher price, but the second type is not. As observed before, with no discriminatory device, the monopolist has to set a reasonable inbred line price in order to benefit from both types of farmers. The monopolist can partially solve this dilemma with the two strategies studied above. With second-period price discrimination, the farmer with high self-production costs is willing to buy inbred line seed at a high price because he then also buys a discount on the second-period price. With a multi-seed strategy, each type of seed is used in the first period to extract some surplus from each type of farmer: the inbred line seed is sold to the first type of farmer, whereas hybrid seed is sold to the second type. As a final point, note that second-period price discrimination always increases surplus, but the multi-seed strategy can lead to a decrease in surplus.

Conclusion

By introducing nondurable crops, seed producers can reduce the competition they face from farmers who self-produce. We analyze the incentives for a monopolist to supply less durable seed, the welfare implications of the introduction of nondurable goods, and how inefficiency can be restored through the introduction of self-production fees. In our setting, self-production is inefficient because the seed producer has lower production costs than farmers.

We analyze pricing decisions and switching decisions in different settings. We consider a monopoly model in which an inbred line seed producer can decide to switch to hybrid seed. We show that hybrid seed can be preferred to inbred line seed, even if it is less efficient, in order to extract more surplus from farmers. The introduction of a self-production fee allows efficiency to improve. We then consider several extensions of our basic framework. First, we investigate what happens when the monopolist cannot commit on future prices. Second, we consider the case where the monopolist can price discriminate in the second period between farmers who did or did not buy seed in the first period. And lastly, we study the incentives for a monopolist to become a multi-seed producer.

Within a simple framework, we attempt to provide an explanation of why producers may have incentives to reduce crop trait durability, even though it is not efficient to do so. We show that the monopolist may introduce a nondurable good for strategic purposes.

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Notes

[1]In genetic terms, inbred line seeds are homozygous. Consequently, if an inbred line is self-pollinated, its offspring is genetically homogeneous and identical to the parent inbred line. Hybrid seeds are heterozygous and result (usually) from the cross of two different inbred lines (Gallais 1990). Hybrid seed performance is greater than that of either of the two inbred parental lines. When a hybrid is self-pollinated, its offspring is heterogeneous, with an average performance closer to that of one of the inbred parental lines, and less than the original hybrid performance.

[2]L'accord CVO Recherché est inscrit dans la loi, Semences et Progrès 2005.

[3]In India, the hybrid wheat introduced by Maharashtra Hybrid Seed spread to 25,000 ha in 2005 (Matuschke and Qaim 2006).

[4]Syngenta has introduced hybrid barley in England and France. See http://www.newfarmcrops.co.uk /Winter%20barley/Home.aspx for England and http://www.orgeshybrides-boost.com for France.

[5]Usually, hybridization based on genetic mechanisms leads to lower production costs. In the case of wheat, hybridization is based on the use of a chemical compound that kills the pollen of the parent female line. In barley, the male sterility of the female parent line is based on a genetic mechanism.

[6]In practice, a fee of 0.5 Euro per ton is collected systematically on harvest and reimbursed to the farmer if he buys the seed or cultivates small areas.

[7]From 2001 to 2006, this fee has generated an average additional profit of 6 million Euros for the wheat breeders, an increase of 20% in their profit from the sale of seeds (Semence

et Progrès 2006).

[8]van Tongeren and Eaton (2004) and Kesan and Gallo (2005) also address this issue in the context of developing countries.

[9]Kesan and Gallo (2005) analyze the impact of such a fee on the incentive to invest in research, but not on the choice of type of seed.

[10]Formally, the model would lead to the same result if we assumed that production costs are equal to zero for the producer and the farmers, but the profit would be $\Pi_L - \theta$ after self-production and Π_L after buying the seed.

[11]The second-period price is set high enough (e.g., $p_{2L} > \theta$) to induce farmers to self-produce seeds.

[12]This assumption simplifies the analysis without qualitatively altering the results. It basically holds if the farmers' comparative disadvantage in self-producing, as well as the heterogeneity in self-production costs, are not "too high." Note that since all farmers self-produce, any price $p_{2L} \geq \Pi_L$ would implement the corner solution of the durable good strategy.

[13]Note that because of the constraint $\Pi_L - p_{1L} \geq 0$, this program is equivalent to the independent maximization of the profit in each period, as if the good was nondurable.

[14]The durable good monopoly payoff is greater than the nondurable good payoff, $2\Pi_L - \bar{\theta} > \Pi_L + \bar{\theta}/4$, as long as $\bar{\theta} < 4\Pi_L/5$, which is always satisfied for $\bar{\theta} \leq \Pi_L/2$. Otherwise, the monopolist chooses the nondurable good strategy which yields a higher welfare. Yet some farmers (but few of them) inefficiently self-produce. Therefore, even when $\bar{\theta} \geq 4\Pi_L/5$, welfare can be improved by reducing self-production if the self-production fee is used as an

incentive tool (see Proposition 1).

[15]We can think of a situation where the monopolist switches to hybrid seed production only in the second period (i.e., after producing inbred line seed in the first period). However, this strategy is obviously dominated from the seed producer's viewpoint.

[16]These details are provided in the appendix posted on AgEconSearch.

[17]The second-period surplus of a farmer is $\Pi_L - \theta$ if he self-produces and zero if he buys the seed.

[18]We thank a referee for pointing this out.

[19]The analysis of a duopoly setting in which an entrant can introduce hybrid seed gives the same kinds of results with a differentiated market. However, the introduction of the fee has no impact on the equilibrium or on its efficiency.

[20]The monopolist has no interest in changing these prices. All of the farmers are willing to buy seed at such prices, so it is worthless to decrease them in order to sell more seed. Conversely, if the monopolist increases these prices, then farmers will no longer buy hybrid seed.

[21]Note that this program is similar to program (1) of the durable good inbred seed monopoly, except that here the monopolist earns $\Pi_H - c$ in the first period from farmers who do not self-produce.

Crop	Surface (Mha)	% Purchased seed	% Hybrid seed
Wheat	5.2	58%	2%
Corn	3.2	100%	100%
Barley	1.6	80%	0%
Canola	1.2	75%	31%
Sunflower	0.6	100%	100%

Source: Semences et Progrès (num 123, 124 and 125). These five crops represent 90% of the cash crop surface in France.

Table 1: Seed market and seed type for the major crops in France (2005)

Strategy	Prices	Monopoly Payoff	Farmers' Surplus	Loss of Welfare
Durable	$p_{1L} = 2\Pi_L - \bar{\theta}$ $p_{2L} = \Pi_L$	$2\Pi_L - \bar{\theta}$	$\frac{\bar{\theta}}{2}$	$\frac{\bar{\theta}}{2}$
Nondurable	$p_{1L} = \Pi_L$ $p_{2L} = \frac{\bar{\theta}}{2}$	$\Pi_L + \frac{\bar{\theta}}{4}$	$\Pi_L - \frac{3\bar{\theta}}{8}$	$\frac{\bar{\theta}}{8}$

Table 2: Inbred line monopoly

Strategy	Prices	Monopoly Payoff	Farmers' Surplus	Welfare loss
Durable	$p_{1L} = \Pi_L - \bar{\theta} - \tau$ $p_{2L} = \Pi_L$	$2\Pi_L - \bar{\theta}$	$\frac{\bar{\theta}}{2}$	$\frac{\bar{\theta}}{2}$
Nondurable $\tau \in [0, \Pi_L - \frac{\bar{\theta}}{2}]$	$p_{1L} = \Pi_L$ $p_{2L} = \frac{\bar{\theta}}{2} + \tau$	$\Pi_L + \frac{\bar{\theta}}{4} + \tau$	$\Pi_L - \frac{3\bar{\theta}}{8} - \tau$	$\frac{\bar{\theta}}{8}$
Nondurable $\tau \in [\Pi_L - \frac{\bar{\theta}}{2}, \Pi_L]$	$p_{1L} = \Pi_L$ $p_{2L} = \Pi_L$	$2\Pi_L - \frac{(\Pi_L - \tau)^2}{\bar{\theta}}$	$\frac{(\Pi_L - \tau)^2}{2\bar{\theta}}$	$\frac{(\Pi_L - \tau)^2}{2\bar{\theta}}$

Table 3: Inbred line monopoly with a self-production fee