Incentive to reduce crop trait durability

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Abstract

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 model we investigate the impact of crop durability on self-production, pricing and switching decisions, and we examine the impact of license fees paid by self-producing farmers. First, in an inbred line seed monopoly model, we find that the monopolist may produce technologically dominated hybrid seed in order to extract more surplus from farmers. Further, the introduction of license fees improves efficiency. Second, we study how the monopolist's behavior is affected by the entry of a nondurable hybrid seed producer. We show that the inbred line seed producer might benefit from competing with a technologically dominated hybrid seed producer, as this allows for consumers' discrimination.

Keywords: Durable good, nondurable good, licenses.

JEL classification: Q16 (R&D and agricultural technology); L12 (Monopoly); L13 (Oligopoly)

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1 Introduction

In Europe and North-America property rights in the seed sector are based on the Plant Breeder's Rights (PBRs) that grant the plant breeder exclusive rights on 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 production cycle. 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 their own seed, farmers directly compete with seed dealers. In this sense, crop traits can be considered as durable goods.

To avoid competition from farmers through seed self-production, 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).[1] This strategy has been followed for corn since the 1950's, sunflowers during the 1970's, and more recently for canola (with partial success) and wheat (without success). Table 1 below shows that the proportion of self-produced seed is important for several major crops (wheat, barley, and canola). With the recent development of biotechnology, firms have tried to develop some genetic artifacts, such as the Genetic Use Restriction Technology or "GURT" (Goeschl and Swanson, 2003), that make the harvested seeds sterile.

Recently, regulations in Europe (and also in Australia and other countries) have reformed intellectual property rights (IPRs) in the seed sector by allowing license fees on crop traits. More precisely, E.U. directive 2100/94 (article 14) indicates that a farmer who self-produces seed should pay a license fee to the innovator that created the seed. In France, the directive has been applied for wheat since 2001, through a tax on the harvest (0.5 Euro per ton, i.e., 4-5 Euros per ha). This tax is reimbursed if the farmer buys the seed or if he cultivates small areas.

[1] In genetic terms, inbred line seeds are homozygous. The consequence is that 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 (generally) from the cross of two different inbred lines (Gallais, 1990). Hybrid seed performance is greater than the performance of the two inbred parental lines. When a hybrid is self-pollinated, its offspring is heterogeneous, with an average performance closer to the performance of the inbred parental lines (i.e., less than the original hybrid performance).

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

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 crops surface in France.

In accordance with the European directive, a large portion of the collected taxes is assigned to the innovator that created the seed varieties (European Union, 1994). More precisely, in 2003-2004 this tax has generated an additional profit of 4.5 million Euros for the wheat breeders, an increase of 18% of their profit from the sale of seeds (Semence et Progrès, 2005).

Therefore, although seed producers cannot legally prevent self-production, they can technologically discourage it by selling nondurable seed. In this context, we investigate the impact of crop durability and license fees on self-production, crop traits, pricing strategies, and decisions to reduce crop durability by switching to hybrid seeds. We also examine how license fees on crop traits improve efficiency.

In our setting, either one type of seed (inbred line seed) or two types of seed (inbred line and hybrid seed) can be produced by seed dealers, whereas farmers can only self-produce inbred line seed. We assume that seed producers are more efficient in producing seed than farmers. Self-production is thus sub-optimal, but it appears to compete with powerful (e.g., monopolistic) seed dealers. We also assume that hybrid seeds are more costly to produce (by seed producers) 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 begin with a benchmark case in which we study a two-period inbred line monopolistic seed industry, whereby the monopolist can commit on future prices. To fully understand the pricing strategies, we first consider that farmers have homogeneous self-production costs. The monopolist can choose between a durable good strategy where she sells inbred line seed to be used in both periods, or a nondurable good strategy where she sells seed during each period. With low farmer self-production costs, she sells seed as a durable good, whereas at a high cost, she sells it as a nondurable good. Due to trait durability, she cuts second-period prices in order to reduce self-production from farmers. Consequently, she extracts strictly less than if the traits were nondurable, i.e., the nondurable monopoly profit.

If the monopolist cannot commit in the first period to the second-period price, the nondurable good strategy is not sustainable. Because farmers make self-production decisions before observing second-period prices, crop trait durability creates a hold-up problem that entails efficiency loss as well as a reduction in the monopoly's market power. The monopolist would like to commit to reduce her price in the second period in order to reduce self-production. However, once farmers have decided not to save part of their harvest to self-produce, they represent a captive demand. Therefore, the monopolist raises her price up to the one-period monopoly price. Expecting this behavior, all farmers self-produce seed, which is inefficient.

However, farmers have heterogeneous self-production costs, and therefore, the nondurable good strategy is always dominated by the durable good strategy. The monopolist sells seed as a durable good to farmers who inefficiently self-produce. The introduction of a license fee increases efficiency by making self-production less attractive. It therefore renders the nondurable good strategy more profitable. It also assigns all efficiency gains to the monopoly. At the limit, when the license fee is equal to the one-period monopoly mark-up (i.e., the monopoly price net of marginal cost), it allows the monopolist to extract all of the surplus.

The introduction of hybrid seed in our analysis yields a number of interesting results. First, if the monopolist cannot produce both inbred line and hybrid seed (thus either switching to hybrid seed production or continuing to produce inbred line seed), we show that she has an incentive to introduce technologically dominated hybrid seed (i.e., hybrid seed less productive than inbred line seed) in order to extract more surplus from farmers. She, indeed, decides to inefficiently shorten the durability of the crop. Furthermore, the license fee reduces the incentive for the monopolist to switch to inefficient hybrid seed. Yet the monopolist switches to hybrid when it is efficient to do so, only for a license fee equal to the one-period monopoly mark-up. Second, if the monopolist can produce the two types of seed, we show that she sells both technologically dominated hybrid seed and inbred line seed to discriminate among farmers.

Finally, we introduce duopoly price competition between an inbred line seed producer and a hybrid seed producer. When hybrid seed is less efficient than inbred line seed, we show that it leads to a differentiated market structure with both types of seeds. This equilibrium is inefficient, because some farmers self-produce, whereas the rest of them use technologically dominated hybrid seeds. The license fee has no impact on efficiency or on the inbred line seed monopoly profit.

As a final introductory point, it is important to keep in mind that royalties on crop traits are motivated by property rights on innovations. The goal of such regulation is that the seed producer gets a full return on his investment in R&D leading to new crop traits, e.g., the monopoly profit yields from a nondurable trait. Accordingly, in our article we examine the impact of such regulation, not only on seed producer profit, but also on the *ex post* efficiency of the entire society.

Further, we restrict ourselves to the study of the monopoly and differentiated duopoly cases because IPRs favor market power, and also because, in our framework, perfect competition leads to *ex post* efficiency. In other words, *ex post* inefficiencies are due to the exercise of market power. However, *ex ante* efficiency might require *ex post* market power due to strong IPRs to foster innovation.

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 reduce prices in the future to attract the residual demand. The monopolist would like to commit on high prices (e.g., the monopoly price), but then is tempted to cut prices to attract the residual demand until it reaches its marginal cost. Expecting this behavior, consumers will buy at marginal cost, at most (Coase, 1972; Bulow, 1982; Gul, Sonnenschein and Wilson, 1986; Waldman, 2003). Here the problem is different. First, 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. She must then commit to setting low prices in the future. Second, since farmers must save and stock part of their harvest to self-produce seed, their choice to render the good durable occurs before observing future prices. Those who have not saved some crop become captive demand: they have no choice but to buy the seed again. The monopolist is thus tempted to increase her price in the future to hold-up these farmers. Expecting this behavior, all farmers save part of their harvest and self-produce. Therefore, conversely to the standard durable good problem, the lack of commitment on future prices leads to a higher (and not lower) price in the future.

Shortening crop trait durability is similar to the planned obsolescence of durable goods (Bulow, 1986; Waldman, 1996). Bulow (1986) has formalized 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 to 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 benefits 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 also 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 the 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 property rights 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).[2] 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 license fees paid by farmers who self-produce.[3]

The paper is organized as follows. The model is presented in section 2. Section 3 is devoted

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

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

to the analysis of the inbred line seed monopoly model. We study pricing strategies in the case of commitment on future prices and in the non-commitment case. Then we investigate how the introduction of license fees affects our findings. Section 4 focuses on the introduction of hybrid seed. We first consider that the monopolist can only decide to switch to hybrid seed production. We investigate how this new strategy alters the monopoly's behavior. We then allow for multi-seed production, and thus investigate whether the monopolist chooses to produce one or both types of seed. In section 5 we analyze a situation in which a firm produces only inbred line seed, and a competitor can enter the market with hybrid seed. Section 6 concludes.

2 The model

We consider a two-period model in which seed producers face a continuum of farmers of mass 1. The discount factor is normalized to 1. Each farmer buys zero or one units of seed. A monopolist produces and sells inbred line seeds (L) at a marginal cost normalized to be 0. As the technology becomes available (at no cost), she (or another seed dealer) may also produce and sell hybrid seeds (H) at a higher marginal cost $c > 0$. The gross payoff of the farmer from using inbred line seed or hybrid seed is Π_j (with $j = H, L$) and is identical for all of the farmers. We suppose that $\Pi_H > \Pi_L$, so that hybrid seeds generate higher a 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 (i.e., the output) can be saved and used to produce seed for the next period's production (as an input). If a farmer buys inbred line seeds at the beginning of the first period, he produces his own second-period seeds at a cost θ that includes the cost of saving part of the harvest. Importantly, farmers differ in their costs of producing inbred line seeds. We assume that θ is distributed according to some density $f(\theta)$ with cumulative function $F(\theta)$ 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. To simplify, we assume that the distribution is uniform and that $\overline{\theta} \leq \Pi_L$.

In our setting, since the seed producer's marginal cost of producing the inbred line is zero, self-production by farmers is socially inefficient. In other words, at the first-best, all seeds are produced by seed producers. Moreover, only one type of seed should be produced at the first-best. To see this, let us consider that a social planner can choose prices and decide on whether to switch to hybrid seeds or to stay with inbred line seeds. He sets the price equal to marginal cost, i.e., zero for inbred line seeds and c for hybrid seeds. Consequently, the two-period welfare is $2\Pi_L$ 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 the incremental cost of producing hybrid line seeds.

Furthermore, it is worth noting that in our setting, 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 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 hybrid seed 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.

3 Inbred line monopoly

We begin with a benchmark analysis in which a monopolist sells only inbred line seed. We investigate her pricing decisions when she can and when she cannot commit in the first period to the second-period price. Assuming that the monopolist can commit on the second-period price is equivalent to assuming that farmers observe this price before deciding to self-produce. This assumption depends on the context. For instance, wheat in France is generally harvested in July and August, and seed for next production cycle is sown either a couple of months later or during the next spring. In the first case of a short time lag between the harvest and the planting, 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. This corresponds to the non-commitment case.

We first analyze the equilibrium when the monopoly can commit in the first period to the second-period price, and we then investigate the non-commitment case. Finally, we analyze the effect of license fees on pricing strategy and welfare.

3.1 Commitment on second-period price

In the commitment case, the timing of events is as follows. In the first period, the monopolist offers a pair of prices $\{p_{1L}, p_{2L}\}$, where p_{1L} (respectively, p_{2L}) is the first-period (respectively, second-period) price. 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 in the first period have to decide whether to buy the seed at price p_{2L}.

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 as a "durable good" in the first period to be used for the two periods, and therefore sells nothing in the second period (the "durable good" strategy), or rather, 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,[4] namely $p_{1L} = 2\Pi_L - \theta$. The monopolist gets the entire surplus, whereas the 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 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. Her choice between the two above pricing strategies

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

depends upon the level of the farmers' self-production costs, θ. Therefore, 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 then 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 be used in the two periods), or she offers the seed during the two periods as a nondurable good. We now give the details of these two strategies.

First, a durable good monopolist sets her prices so as to sell to self-producing farmers in the first period, and to the others (if any) in the second period. The second period price is the farmer's reservation price $p_{2L} = \Pi_L$. A farmer whose self-production cost is θ buys 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 $\widetilde{\theta} \leq \bar{\theta}$. The monopoly's program is thus

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

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 $p_{2L} = \Pi_L$. The monopoly two-period payoff is therefore $\Pi_L + \Pi_L^2/4\bar{\theta}$. At the same time, each farmer whose cost is $\theta \geq \Pi_L/2$ (who buys only during the first period and self-produces) gets a payoff of $\Pi_L/2 - \theta$, while the others (who buy only during the second period at price Π_L) get zero. The farmers' total surplus is $\Pi_L^2/8\bar{\theta}$. The loss of welfare is due to (i) inefficient self-production from farmers $\theta \leq \Pi_L/2$ for a total cost $\Pi_L^2/8\bar{\theta}$ and (ii) no production in the first period for farmers $\theta > \Pi_L/2$, which yields to a loss of $\Pi_L^2 - \Pi_L^2/2\bar{\theta}$. The total welfare is therefore $\Pi_L + 3\Pi_L^2/8\bar{\theta}$.[5]

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. The monopoly's payoff is $2\Pi_L - \bar{\theta}$, whereas each farmer whose cost is θ gets a payoff of $\bar{\theta} - \theta$. The farmers' total surplus is thus $\bar{\theta} - E[\theta] = \bar{\theta}/2$. The total welfare is $2\Pi_L - \bar{\theta}/2$, and therefore, the welfare loss is the expected cost $\bar{\theta}/2$ (recall that the first-best welfare is $2\Pi_L$).

[5] The total welfare can be computed by subtracting the total loss $\Pi_L^2/8\bar{\theta} + \Pi_L^2 - \Pi_L^2/2\bar{\theta}$ from the first-best welfare $2\Pi_L$ or by adding the monopolist's and the farmers' surplus, respectively $\Pi_L + \Pi_L^2/4\bar{\theta}$ and $\Pi_L^2/8\bar{\theta}$.

Second, a nondurable good monopolist sells the 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 seeds. 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

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

The optimal prices are therefore $p_{1L} = \Pi_L$ and $p_{2L} = \bar{\theta}/2$. The monopolist sells to all of the farmers in the first period and to only half of them (i.e., those whose θ is larger than $\bar{\theta}/2$) in the second period. She makes a profit of $\Pi_L + \bar{\theta}/4$.

In any case, the durable good strategy dominates the nondurable good strategy, as the monopolist gets a higher payoff from choosing the durable good strategy. Indeed, if $\bar{\theta} > \Pi_L/2$ (respectively, $\bar{\theta} \leq \Pi_L/2$), the durable good payoff is greater than the nondurable good payoff, $\Pi_L + \Pi_L^2/4\bar{\theta} > \Pi_L + \bar{\theta}/4$ (respectively, $2\Pi_L - \bar{\theta} > \Pi_L + \bar{\theta}/4$), as long as $\bar{\theta} \leq \Pi_L$ (respectively, $\bar{\theta} < 4\Pi_L/5$). By assumption, $\bar{\theta} \leq \Pi_L$, and $\bar{\theta} < 4\Pi_L/5$ is always satisfied for $\bar{\theta} \leq \Pi_L/2$. Therefore, she only sells seed in the first period, but to all of the farmers. This leads to an inefficient outcome, as all of the farmers inefficiently self-produce in the second period.

3.2 No commitment on second-period price

We now consider what happens when the monopolist cannot commit on future prices or, equivalently, when the farmers observe the second-period price after deciding whether to self-produce or not. Therefore, the timing of events is now different, and is the following. The first period consists of three stages. First, the monopolist sets the first-period price, p_{1L}. Second, the farmers observe this price and each of them decides whether or not to buy inbred line seeds. Third, each farmer decides whether or not to save some seed to self-produce in the second period. The second period consists of two stages. First, the monopolist sets the second-period price, p_{2L}. Second, the farmers observe this new price, and those who did not self-produce have to decide whether or not to buy seeds. In the absence of any commitment device, we solve the two-period model backward and we determine the Subgame Perfect Nash equilibrium.

First, consider the case of homogenous farmers, where all of the farmers have the same self-production cost θ. With commitment on future prices, we already know that the monopolist chooses the nondurable good strategy if $\theta > \Pi_L/2$. She sells seed during the two periods to all of the farmers at prices $p_{1L} = \Pi_L$ and $p_{2L} = \theta$, respectively. When the monopolist cannot commit on future prices, the nondurable good strategy is not subgame perfect: she is tempted to raise the second-period price from θ to Π_L. Furthermore, farmers face a hold-up problem. The logic is the following. In the second period, farmers who did not save their harvest to self-produce become captive consumers. Therefore, the monopolist can set her second-period price equal to the seed value, Π_L. Expecting that price, none of the farmers buy the second-period seed. Indeed, they are better off if they self-produce, as $\Pi_L - p_{2L} < \Pi_L - \theta$ is always satisfied when $p_{2L} = \Pi_L$. A lower second-period price will induce farmers not to save, and thus, to buy from the monopoly in the second period. However, this cannot be an equilibrium, as the monopolist will always be tempted to raise her second period price up to Π_L, forcing farmers to buy at this price. Anticipating this behavior, all of the farmers who bought seed in the first period will save seed in the first period for second-period production.

We now turn to the heterogeneous case where θ is uniformly distributed on $[0, \bar{\theta}]$. With commitment on future prices, the durable good strategy dominates the nondurable good strategy. The committed second-period price is the subgame perfect second-period price $p_{2L} = \Pi_L$. Therefore, the equilibrium prices of the commitment game are also those of the non-commitment game. The outcome is thus the same. It is inefficient because some farmers self-produce seed inefficiently (all of the farmers if $p_{1L} = 2\Pi_L - \bar{\theta}$) and some produce only in the second period if $p_{1L} = 3\Pi_L/2$.

We now examine the impact of a royalty fee on the monopolist's strategy. For expositional simplicity,[6] we focus on the case where $\bar{\theta} \leq \Pi_L/2$.

3.3 Monopoly pricing strategy with license fees

As mentioned in the introduction, following a new E.U. directive, farmers who self-produce must pay a tax that is assigned to the seed producer. Thus we investigate the impact on the monopoly pricing strategy of a given license fee τ paid by farmers who self-produce. We assume that $0 < \tau \leq \Pi_L$ and $\bar{\theta} \leq \Pi_L/2$.

[6] For $\bar{\theta} > \Pi_L/2$, we obtain qualitatively similar results.

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

However, the imposition of a license fee makes self-production more costly, and makes the nondurable good strategy more attractive for the monopolist. To see this, consider the non-commitment case. As before, the lack of commitment implies that the second-period price will be the highest possible, namely $p_{2L} = \Pi_L$. Expecting this price, and with the imposition of license fees, some farmers will no longer self-produce seeds. Figure 1 illustrates this result.

Insert figure 1

Farmers with low self-production costs, i.e., $\theta < \Pi_L - \tau$, still prefer to self-produce and only earn $\Pi_L - \tau - \theta$, where τ is transferred to the monopoly in the second period. Farmers with high self-production costs earn a negative profit by self-producing, and consequently prefer to buy seeds in the second period at price $p_{2L} = \Pi_L$. Some farmers prefer to buy seed only if the license fee is high enough (i.e., $\tau > \Pi_L - \bar{\theta}$). When choosing the nondurable good strategy the monopoly two-period payoff is $2\Pi_L - (\Pi_L - \tau)^2/\bar{\theta}$ (by using figure 1 it is straightforward to determine the profit; the formal proof is relegated to the appendix).

The monopolist prefers to sell seed as a nondurable good as soon as some farmers are willing to buy seed at the second-period price $p_{2L} = \Pi_L$. Or, in other words, when the level of the license fee is high enough, i.e., $\tau > \Pi_L - \bar{\theta}$. If this condition is fulfilled, the monopolist gains more by adopting a nondurable good strategy than a durable good strategy, not only from the farmers who self-produce, but also from those who buy in the second period. The logic is as follows. First, consider a farmer who self-produces. If the monopolist chooses a durable good strategy, she earns $2\Pi_L - \bar{\theta} - \tau + \tau$ per unit by setting a first-period price of $2\Pi_L - \bar{\theta} - \tau$. If she chooses the nondurable good strategy, she earns $\Pi_L + \tau$ per unit by setting a first-period price of Π_L. As the license fee increases, the first-period price of a durable good monopoly decreases, whereas the first-period price of a nondurable good monopoly does not vary. As long as $\tau > \Pi_L - \bar{\theta}$, the nondurable good strategy yields a higher payoff. Second, consider a farmer who buys seed in the second period when the seed is sold as a nondurable good. The durable good monopolist still earns $2\Pi_L - \bar{\theta}$, and the nondurable good monopolist earns the full surplus $2\Pi_L$. Therefore, if $\tau > \Pi_L - \bar{\theta}$ a nondurable good monopolist earns more from farmers who self-produce ($\Pi_L + \tau > 2\Pi_L - \bar{\theta}$) and also from those who buy ($2\Pi_L > 2\Pi_L - \bar{\theta}$).

The choice of the nondurable good strategy leads to an increase in the total surplus, since inefficient farmers with high self-production costs buy seed that is efficiently produced. The increase in surplus is due to the saved self-production cost θ from farmers who no longer self-produce and from an increase in monopoly profit of $\bar{\theta}$ (increase in price and tax over the two periods). Hence, the increase in the monopoly profit from the introduction of a significant tax is greater than the increase in total surplus.

In the extreme case, where $\tau = \Pi_L$, the monopolist extracts all of the surplus. Only farmers with null production costs self-produce and pay royalties. All of the other farmers buy seed during each period at the one-period monopoly price Π_L.[7]

To summarize (see figure 2), for low values of the fee, i.e., $\tau \in (0, \Pi_L - \bar{\theta}]$, the monopolist adopts the durable good strategy and sells seed only in the first period at price $2\Pi_L - \bar{\theta} - \tau$. She makes a profit of $2\Pi_L - \bar{\theta}$, and farmers get a surplus of $\bar{\theta}/2$. Therefore, the total surplus is $2\Pi_L - \bar{\theta}/2$. For higher values of the fee, i.e., $\tau \in [\Pi_L - \bar{\theta}, \Pi_L]$, the monopolist adopts the nondurable good strategy and sells seed during both periods at prices $p_{1L} = p_{2L} = \Pi_L$. She gets a profit of $2\Pi_L - (\Pi_L - \tau)^2/\bar{\theta}$, and farmers get a surplus equal to what they save by self-producing, $(\Pi_L - \tau)^2/2\bar{\theta}$. The total surplus is then $2\Pi_L - (\Pi_L - \tau)^2/2\bar{\theta}$. The inefficiency loss due to self-production is therefore $(\Pi_L - \tau)^2/2\bar{\theta}$.

Insert figure 2

We sum up the previous analysis in the following proposition.

Proposition 1 *By reducing self-production, a license fee $\tau > \Pi_L - \bar{\theta}$ increases efficiency and transfers more than the efficiency gain to the monopolist. When $\tau = \Pi_L$, efficiency is restored and the monopolist gets all of the surplus.*

[7] License fees are distributed to all through lump-sum subsidies, the efficiency gains are then more equitably shared. Although it is not the purpose of this regulation that is intended to provide the seed producer a return on her investment in R&D, such a redistribution might be more acceptable from the farmers' viewpoint.

4 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 have to decide which one to buy. If they buy hybrid seed in the first period, they cannot use part of the harvest to self-produce in the second period. Thus, in the second period, they have to buy either the inbred line seed at price p_{2L} or the hybrid seed at price p_{2H}.

In this setting, we investigate under what circumstances the monopolist decides to switch to hybrid production, or to produce both inbred line and hybrid seeds at the same time. We thus investigate whether the inbred line producer introduces technologically dominated hybrid seed. As a benchmark, we first assume that the monopolist can only produce one type of seed (hybrid or inbred line), e.g., for technological, legal and/or marketing reasons. We then allow the monopolist to sell both seeds.

4.1 Switching from inbred line seed to hybrid seed

We first consider that the monopolist can only produce one type of seed, and can commit on future prices. In this setting, the timing of events is the following. The first period consists of three stages. First, the monopolist decides whether to switch to hybrid or to keep producing inbred line seed. Second, she sets the seed prices accordingly. Third, farmers observe the prices, as well as the type of seed produced, and decide to buy or not. They also decide whether to save part of their harvest for self-production for the next period if inbred line seed are produced. In the second period, if inbred line seed is produced, farmers who did not save seeds have to decide whether to buy or not. If hybrid seeds are produced, farmers have no choice but to buy the seed in the second period.

If the monopolist switches to hybrid seed in the first period, she behaves as a nondurable good monopolist, and thus, sets the monopoly price in each period, i.e., $p_{1H} = p_{2H} = \Pi_H$. None of the farmers can use their own seed for the next period, and they all buy seeds at their valuation, Π_H. The two-period benefit of the monopoly is, therefore, $2(\Pi_H - c)$, and farmers get a null benefit. Note that in this case, whether the monopolist can or cannot commitment on future prices does not matter.

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 $2\Pi_L - \bar{\theta}$. Thus, the monopolist switches to hybrid seed in the first period[8] if $c \leq \Delta\Pi + \bar{\theta}/2$. However, from a social viewpoint, hybrids should be produced only if $c < \Delta\Pi + \bar{\theta}/4$.

Depending on the value of c, four areas can be defined (see Figure 3 for $\tau = 0$). (1) If $c < \Delta\Pi$, the monopolist switches to hybrid seed, which is also the most efficient technology (first-best choice). (2) If $c \in [\Delta\Pi, \Delta\Pi + \bar{\theta}/4]$, the dominated hybrid seed is produced. This is because by avoiding self-production, hybrid technology allows the monopolist to extract all of the surplus, even if this is less efficient. This switch is efficient (i.e., leads to a higher surplus than the surplus gained from the inbred line seed) in a monopoly framework because the price schedule with inbred line seed leads farmers to inefficiently self-produce seed. (3) If $c \in [\Delta\Pi + \bar{\theta}/4, \Delta\Pi + \bar{\theta}/2]$, the dominated hybrid seed is still produced, for the same reason as in (2). However, this switch is now inefficient, as hybrid seed is becoming excessively inefficient, even if it avoids inefficient self-production. (4) If $c > \Delta\Pi + \bar{\theta}/2$, the monopolist keeps producing inbred line seed, which corresponds to an efficient choice.

Insert figure 3

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 efficient as long as $c \leq \Delta\Pi + \bar{\theta}/4$.*

We now investigate whether the introduction of license fees can provide the monopolist with incentives to switch to hybrid seed when it is efficient to do so. Figure 3 represents how the four areas described earlier are affected by the license fee.

When $\tau \in (0, \Pi_L - \bar{\theta}]$, we already know that the introduction of a license fee has no effect on the monopoly equilibrium, including prices, profits and welfare. Therefore, a small fee τ cannot give enough incentive to switch to hybrid seed. For $\tau \in [\Pi_L - \bar{\theta}, \Pi_L]$, the inbred line

[8] 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.

monopolist chooses the nondurable good strategy. The profit and the total welfare derived in the previous section (that both depend on τ) can be used to examine the monopolist's switching strategy. She switches to hybrids when $c \leq \Delta\Pi + (\Pi_L - \tau)^2/2\bar{\theta}$ (areas 1, 2 and 3), which is efficient only for $c \leq \Delta\Pi + (\Pi_L - \tau)^2/4\bar{\theta}$ (areas 1 and 2). The "inefficiency area" (area 3) in which the monopolist switches to hybrid seed, although it is efficient to keep producing inbred line seed, shrinks as τ increases. This is because a higher license fee increases the profit of the inbred line seed monopoly and, therefore, makes the switch to dominated hybrid seed less attractive. Yet this inefficiency area exists as long as $\tau < \Pi_L$, meaning that imposing a license 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 license fee makes the monopolist switch inefficiently to hybrids less often. She always switches efficiently only when the license fee allows her to capture all of the surplus with inbred line seeds, i.e.,* $\tau = \Pi_L$.

4.2 Multi-seed production

We now analyze what happens when the monopolist can sell both types of seeds. If hybrid seed is more efficient than inbred line seed, i.e., $c < \Delta\Pi$, the monopolist has no incentive to sell both types of seed. She only sells hybrid seed and this has two advantages: it enables making a higher profit because of higher efficiency; it enables the extraction all of the surplus because it is a nondurable good, in the sense that farmers are captive in the second period. The monopolist charges prices $p_{1H} = p_{2H} = \Pi_H$, and therefore earns $2(\Pi_H - c)$, whereas farmers get a null payoff.

On the other hand, if inbred line seed is more efficient than hybrid seed, i.e., $c > \Delta\Pi$, the monopolist can introduce inefficient hybrid seed in the first period to force farmers to buy inbred line seed in the second period. To see this, let us study the possible strategies of the monopolist for each period. In the second period, if the monopolist sells one type of seed, it will be the inbred line seed at price $p_{2L} = \Pi_L$. Indeed, because of our two-period framework, the monopolist provides only the most efficient seed in the second period, which yields a payoff of

Π_L that is greater than $\Pi_H - c$. In the first period the picture is more complex. If both types of seed are provided at prices p_{1L} and p_{1H}, farmers with low self-production costs buy inbred line seed and self-produce,[9] whereas those with high self-production costs buy hybrid seed in the first period and inbred line seed in the second period. A farmer whose self-production cost is θ chooses the first strategy if $\Pi_L - p_{1L} + \Pi_L - \theta \geq \Pi_H - p_{1H} + \Pi_L - p_{2L}$ or, equivalently, if $\theta \leq 2\Pi_L - \Pi_H - p_{1L} + p_{1H} \equiv \tilde{\theta}$. Thus, given the second-period price $p_{2L} = \Pi_L$, the monopolist chooses p_{1L} and p_{1H} that solve

$$\begin{cases} \max\limits_{p_{1L}, p_{1H}} p_{1L} \int_0^{\tilde{\theta}} f(\theta) d\theta + (p_{1H} - c + \Pi_L) \int_{\tilde{\theta}}^{\bar{\theta}} f(\theta) d\theta \\ \text{subject to} \quad \tilde{\theta} = \min\{2\Pi_L - \Pi_H - p_{1L} + p_{1H}, \bar{\theta}\}, \\ \qquad\qquad\quad\; p_{1H} \leq \Pi_H, \\ \qquad\qquad\quad\; p_{1L} > p_{1H} - \Delta\Pi. \end{cases} \tag{2}$$

The last constraint means that the monopolist needs to make sure that no farmer buys inbred line seed instead of hybrid seed in the first period for a one period use only. The price solutions for this program (calculations are relegated to the appendix) are

$$\begin{aligned} p_{1H} &= \Pi_H, \\ p_{1L} &= \begin{cases} \frac{1}{2}(3\Pi_L + \Pi_H - c) & \text{if } c < \Delta\Pi + 2\bar{\theta}, \\ 2\Pi_L - \bar{\theta} & \text{if } c \geq \Delta\Pi + 2\bar{\theta}. \end{cases} \end{aligned}$$

To summarize, a multi-seed monopolist adopts the following pricing strategies. When $c \in [\Delta\Pi, \Delta\Pi + 2\bar{\theta}]$, she sells both inbred line and hybrid seeds at respective prices $p_{1L} = (3\Pi_L + \Pi_H - c)/2$ and $p_{1H} = \Pi_H$ in the first period, and only inbred line seed in the second period at price $p_{2L} = \Pi_L$. Farmers with cost $\theta \leq \tilde{\theta} = (c - \Delta\Pi)/2$ buy inbred line seed in the first period and self-produce in the second period. The rest of the farmers buy hybrid seed in the first period and inbred line seed in the second period. When $c \geq \Delta\Pi + 2\bar{\theta}$, the monopolist sells only inbred line seed during the two periods at prices $p_{1L} = 2\Pi_L - \bar{\theta}$ and $p_{2L} = \Pi_L$. Therefore, all of the farmers self-produce.

Figure 4 is helpful in understanding the gain and loss from the multi-seed strategy (the formal expressions are derived in the appendix).

[9] At monopoly prices, the only reason to buy inbred line seed is to exploit its durability.

$\boxed{\text{Insert figure 4}}$

The total loss of welfare compared to the first-best outcome with only inbred line seed and no self-production (namely $2\Pi_L$) is

$$\tfrac{(c-\Delta\Pi)^2}{8\bar{\theta}} + (1 - \tfrac{c-\Delta\Pi}{2\bar{\theta}})(c - \Delta\Pi). \tag{3}$$

The first term represents the efficiency loss due to self-production (area I in figure 4), whereas the second term represents the efficiency loss due to the use of inefficient hybrid seed (area II in figure 4). Furthermore, to determine whether a multi-seed setting situation is efficient, we need to compare the above loss to the inefficiency loss due to self-production from all of the farmers, $\bar{\theta}/2$. Therefore, we find that it is efficient to introduce hybrid seed in a monopoly setting when $c \leq \Delta\Pi + 2\bar{\theta}/3$ (calculations are relegated to the appendix). This leads to the following proposition.

Proposition 4 *When the monopolist has the option to sell both hybrid and inbred line seeds during the same period, she introduces technologically dominated hybrid seed if* $c \in [\Delta\Pi, \Delta\Pi+2\bar{\theta}]$. *This is efficient only when* $c \leq \Delta\Pi + 2\bar{\theta}/3$.

Even if inbred line seed is more efficient, the monopolist can extract more surplus by also selling hybrid seed. This is because when she produces only inbred line seed, she serves all of the demand.[10] She thus has to match her price with the less efficient farmers' willingness to pay for a durable good $\bar{\theta}$. With hybrid seed, she can discriminate among farmers by providing the less efficient ones (i.e., those with high θ) with hybrid seed, thereby increasing the price for the more efficient ones (i.e., those with low θ). Hence, she increases the rent extracted from the more efficient farmers.

We now investigate the effect of a license fee on the decision to introduce hybrid seed. We first derive the optimal multi-seed monopoly payoff with a license fee (see appendix for calculation), and we then compare it with the mono-seed monopoly payoff when only inbred line seed is produced.

If $c < \Delta\Pi + 2\bar{\theta}$ the solutions are $p_{1L} = \max\{(3\Pi_L + \Pi_H - c)/2 - \tau, \Pi_L\}$ and $p_{1H} = \Pi_H$. First, if $\tau < \Pi_L - (c - \Delta\Pi)/2$, the monopoly profit is not affected by the license fee because

[10] This is the case at least when $\bar{\theta} \leq \Pi_L$.

the monopolist decreases the price charged to self-producing farmers by the same amount as the fee she gets from these farmers when they buy the seed. Second, if $\tau > \Pi_L - (c - \Delta\Pi)/2$, the optimal inbred line seed price is Π_L. In this case, the monopolist does not use hybrid seed as a discriminatory device any longer, because she can extract a larger part of the self-producing farmers' profits with a high license fee. If the monopolist chooses to sell hybrid seed, she then chooses a price p_{1L} slightly higher than Π_L. Only farmers with $\theta \leq \Pi_L - \tau$ would self-produce. The monopoly profit would decrease with τ, as shown in figure 5. This strategy leads to a lower profit than when the monopolist chooses a p_{1L} slightly lower than Π_L and produces only inbred line seed in the first period.

Insert figure 5

If $c \geq \Delta\Pi + 2\bar{\theta}$ in the absence of a license fee, the multi-seed monopolist prefers to sell only inbred line seed as a durable good ($p_{1L} = 2\Pi_L - \bar{\theta}$). The situation is, therefore, identical to the one we studied before, with a monopolist selling only inbred line seed. With the introduction of license fees, the monopolist still prefers to sell only inbred line seed.

When $c < \Delta\Pi + 2\bar{\theta}$, in the presence of a license fee, the monopolist can choose either to introduce the hybrid in the first period, or to produce inbred line seed as a nondurable good, as we have seen in the previous section. We now analyze the monopolist's decisions. When she sells both seeds, two cases must be considered, depending on whether τ is smaller or greater than $\Pi_L - (c - \Delta\Pi)/2$ (see figure 5). On the other hand, when the monopolist sells only inbred line seed as a nondurable good, two cases are also possible, depending on whether τ is greater or smaller than $\Pi_L - \bar{\theta}$ (see figure 2). Further, if $c < \Delta\Pi + 2\bar{\theta}$, then $\Pi_L - \bar{\theta} < \Pi_L - (c - \Delta\Pi)/2$, so that only the three following cases need to be considered.

First, if $\tau < \Pi_L - \bar{\theta}$, the license fee does not affect the monopoly payoff or the surplus, whatever the strategy (hybrid and inbred line seed or only inbred line seed as a nondurable good). The results are identical to those obtained earlier with no license fee (see proposition 4).

Second, if $\tau \in [\Pi_L - \bar{\theta}, \Pi_L - (c - \Delta\Pi)/2]$, the license fee affects the monopoly payoff and the surplus when only inbred line seed is produced as a nondurable good. The monopolist prefers to sell both seeds in the first period if $c < \Gamma_1$ (see appendix for details of the calculation). The surplus increases when both seeds are produced in the first period if $c < \Gamma_2$ (see appendix for details of the calculation).

Third, if $\tau > \Pi_L - (c - \Delta\Pi)/2$ (or, equivalently, $c > \Delta\Pi + 2(\Pi_L - \tau)$) the monopolist gets a lower profit from selling both seeds compared to the case where $\tau < \Pi_L - (c - \Delta\Pi)/2$ (see figure 5) and this level is lower compared to the case where only inbred line seed is sold (the condition $c < \Gamma_1$ is never satisfied). Hence the monopolist is always better off if she sells only inbred line seeds, which is also the situation where the surplus is greater.

Figure 6 provides a synthetic representation of these three cases. The arguments for areas (1) to (4) are identical to those provided for figure 3.

Insert figure 6

5 Differentiated duopoly

In this section we consider a duopoly model in which a monopolist produces inbred line seed and a potential entrant produces hybrid seed. We assume that the inbred line seed producer cannot produce hybrid seed, for instance, for technical or legal reasons, but that another firm can. In this new setting, the two firms compete with different seeds. Each seed producer sets a price p_{tj} in each period $t = 1, 2$ for $j = H, L$, and prices are chosen simultaneously.

Because pricing strategies are different once competition is introduced, we investigate whether technologically dominated seed is still introduced, and why and how it affects efficiency. We also examine the impact of license fees on self-produced seed.

First, if hybrid seed production is a more efficient technology, i.e., $c < \Delta\Pi$, the hybrid producer excludes the inbred line producer by pricing just below $\Delta\Pi$ during both periods. It is a monopoly contestable market.

Second, if both seeds are equally efficient for one period, i.e., $c = \Delta\Pi$, the firms compete à la Bertrand in the second period and set their prices at marginal cost, i.e., $p_{2L} = 0$ and $p_{2H} = c$. Expecting these prices, no farmers self-produce, since self-production costs exceed seed prices. Therefore, all of the farmers buy seeds as nondurable goods in the first period. Seed producers compete à la Bertrand in the first period and they also set prices at marginal cost.

Third, if inbred line seeds are more efficient than hybrid seeds, i.e., $c > \Delta\Pi$, the equilibrium is such that only inbred line seed is produced in the second period. Indeed, in the second period, the farmers who did not self-produce become captive. Seed producers are in a one-period Bertrand competition for this captive demand. Since inbred line seed dominates hybrid seed, the inbred line producer can set a low price to capture all of the demand, $p_{2L}^* = c - \Delta\Pi - \varepsilon$ (with ε close to 0). The hybrid producer has no demand, even if he sets his price at marginal cost c. Farmers always buy from the inbred line producer, as $\Pi_H - c < \Pi_L - p_{2L}^*$ if they do not self-produce. However, farmers whose cost θ is lower than $p_{2L}^* = c - \Delta\Pi$ self-produce.

In the first period, seed producers are engaged in a price competition with differentiated seeds. Farmers rank seeds according to their self-production costs: those with low θ have a higher willingness to pay for the durable seed. The inbred line seed producer targets farmers with low θ, who then self-produce seed, whereas the hybrid producer sells to those with high θ who buy seeds during each period. Formally, for a given p_{1L} and p_{1H}, farmer θ prefers to buy inbred line seed and self-produce seed, rather than buying hybrid seed in the first period, and inbred line seed in the second period, if $\Pi_L - p_{1L} + \Pi_L - \theta \geq \Pi_H - p_{1H} + \Pi_L - p_{2L}$. Therefore, all farmers with $\theta \leq \widetilde{\theta} \equiv \min\{p_{1H} - p_{1L} + c - 2\Delta\Pi, \bar{\theta}\}$ buy inbred line seed. Thus, when choosing the first-period price, the inbred line seed producer solves

$$\underset{p_{1L}}{Max} p_{1L} \int_0^{\widetilde{\theta}} f(\theta)d\theta + p_{2L}^* \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta)d\theta. \tag{4}$$

Therefore, she trades first period profits for second period profits. By setting a lower first-period price, she attracts more farmers in the first period who are willing to self-produce. But those farmers will not buy seed in the second period, and therefore, the second-period demand and profit will be reduced. When $\widetilde{\theta} < \bar{\theta}$, the first-order condition yields the inbred line seed producer's best response to any price p_{1H}

$$p_{1L} = \frac{2c - 3\Delta\Pi + p_{1H}}{2}. \tag{5}$$

Symmetrically, for a given p_{1L}, the hybrid seed producer's first-period price solves

$$\underset{p_{1H}}{Max} (p_{1H} - c) \int_{\widetilde{\theta}}^{\bar{\theta}} f(\theta)d\theta.$$

When $\widetilde{\theta} < \bar{\theta}$, the first-order condition yields the hybrid seed producer's best response to any price p_{1L}

$$p_{1H} = \frac{\bar{\theta} + p_{1L}}{2} + \Delta\Pi. \tag{6}$$

The best responses (5) and (6) yield a unique Nash equilibrium (p^e_{1L}, p^e_{1H}) defined as

$$p^e_{1L} = \tfrac{4(c-\Delta\Pi)+\bar{\theta}}{3} \qquad \text{and} \qquad p^e_{1H} = \tfrac{2c+\Delta\Pi+2\bar{\theta}}{3}.$$

Prices (p^e_{1L}, p^e_{1H}) are the equilibrium prices at which selling at price p^e_{1H} is profitable for the hybrid seed producer, i.e., $p^e_{1H} \geq c$. In the opposite case, if $p^e_{1H} < c$, or equivalently $c > \Delta\Pi + 2\bar{\theta}$, the hybrid seed producer has no choice but to price at marginal cost $p^c_{1H} = c$, whereas the inbred line seed producer chooses her best response to this price, $p^c_{1L} = 3(c - \Delta\Pi)/2$. The hybrid seed producer is thus excluded from the market and $\widetilde{\theta} = \bar{\theta}$. All farmers buy inbred line seed as a durable good because, since $c > \Delta\Pi + 2\bar{\theta}$, the second-period price $p^*_{2L} = c - \Delta\Pi$ is higher than the highest self-production cost $\bar{\theta}$.

To summarize, when $\Delta\Pi < c \leq \Delta\Pi + 2\bar{\theta}$, seed producers compete in prices in a differentiated market. Farmers with low self-production costs buy inbred line seed in the first period and self-produce in the second period. Farmers with high self-production costs buy hybrid seed in the first period and inbred line seed in the second period. When $c > \Delta\Pi + 2\bar{\theta}$, the hybrid seed producer is excluded from the market. The inbred line seed producer sells seed in the first period to all of the farmers, who then self-produce.

In any case, duopoly pricing leads to inefficient self-production by farmers as long as $c > \Delta\Pi$. Moreover, farmers who do not self-produce buy technologically dominated hybrid seed, which is also inefficient. Thus, if $c > \Delta\Pi$, the presence of hybrid seed reduces self-production, but by detrimentally using an inefficient technology. Moreover, the threat of competition from the hybrid seed producer in the second period bounds the inbred line second-period price. Thus it mitigates the hold-up problem highlighted in the inbred line monopoly case, with no commitment to the benefit of the inbred line producer.

When we investigate the impact of a license fee on seed self-production in this duopoly setting, we find that a fee $\tau > 0$ has no impact on seed prices and market structure (see appendix for details of the calculation).

We summarize the duopoly findings in the following proposition.

Proposition 5 *When $\Delta\Pi + 2\bar{\theta} \geq c > \Delta\Pi$ in a duopoly setting, the inbred line seed producer sells seed as a durable good to farmers with low self-production cost, whereas the hybrid seed* *producer sells only to farmers who use seed as a nondurable good. This differentiated market structure is inefficient, because self-produced seeds, as well as hybrid seeds, are technologically dominated. A license fee on self-produced seeds has no impact on the market equilibrium or, therefore, on its efficiency.*

6 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 license 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 first 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 license fee allows efficiency to be restored. Second, we consider the incentives for a monopolist to become a multi-seed producer. Even though hybrid seed is less efficient, the monopolist can decide to produce both types of seed. The introduction of a license fee can also restore efficiency. Lastly, we consider the situation in which an inbred line monopolist faces potential entry by a hybrid producer. In this duopoly setting, the monopolist has an incentive to let the hybrid producer enter the market in order to create differentiation. In this last case, the introduction of a license fee has no effect on pricing strategies.

Within a simple framework, we attempt to provide an explanation of why producers may have some 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.

Appendix

1. Monopoly pricing strategy with royalty

When the monopolist charges a price equal to Π_L during each period, and farmers with self-production costs higher than $\widehat{\theta}_\tau = \Pi_L - \tau$ buy seeds in the second period, the two period profit of the monopolist is

$$\Pi_L + \tau \int_0^{\widehat{\theta}_\tau} f(\theta)d\theta + \Pi_L \int_{\widehat{\theta}_\tau}^{\overline{\theta}} f(\theta)d\theta = 2\Pi_L - \frac{(\Pi_L - \tau)^2}{\overline{\theta}}.$$

2. Multi-seed monopolist

The objective function represented in program (2) can be simplified to

$$\frac{1}{\bar{\theta}} \left[\tilde{\theta}(2\Pi_L - \Pi_H + p_{1H} - \tilde{\theta}) + (\bar{\theta} - \tilde{\theta})(p_{1H} - c + \Pi_L)) \right].$$

Note that it is equivalent to maximizing the objective function on $\tilde{\theta}$ instead of p_{1L}, so that the monopoly's program becomes

$$\begin{cases} \max\limits_{\tilde{\theta}, p_{1H}} \frac{1}{\bar{\theta}} \left[\bar{\theta}(p_{1H} + \Pi_L - c) + \tilde{\theta}(\Pi_L - \Pi_H + c - \tilde{\theta}) \right] \\ \text{subject to} \quad p_{1L} = 2\Pi_L - \Pi_H - \tilde{\theta} + p_{1H}, \\ \qquad\qquad\quad 0 \leq \tilde{\theta} \leq \bar{\theta}, \\ \qquad\qquad\quad p_{1H} \leq \Pi_H, \\ \qquad\qquad\quad p_{1L} > p_{1H} - \Delta\Pi. \end{cases}$$

The solutions are $p_{1H} = \Pi_H$ and $\tilde{\theta} = \min\{(c - \Delta\Pi)/2, \bar{\theta}\}$. If $\frac{1}{2}(c - \Delta\Pi) < \bar{\theta}$, the upward constraint on $\tilde{\theta}$ is not binding, and therefore, $p_{1L} = (3\Pi_L + \Pi_H - c)/2$. Further, it is easy to check that $p_{1L} > p_{1H} - \Delta\Pi = \Pi_L$, as $\Delta\Pi + 2\bar{\theta} < \Pi_L + \Pi_H$. Otherwise, if $(c - \Delta\Pi)/2 \geq \bar{\theta}$, it is binding, and thus, the monopoly sells only inbred line seed in the first period at price $p_{1L} = 2\Pi_L - \bar{\theta}$. Note that since, by assumption, $c - \Delta\Pi > 0$, the downward constraint on $\tilde{\theta}$ is never binding. Here again, it is easy to check that $p_{1L} > \Pi_L$, as $2\Pi_L - \bar{\theta} > \Pi_L$.

2.1. Producer's profit and farmers' surplus with multi-seed monopoly

With a multi-seed monopoly, farmers whose self-production cost is smaller than $\tilde{\theta}$ get a surplus $\tilde{\theta} - \theta$ by buying inbred line seed and self-producing, whereas farmers with a cost of $\theta \geq \tilde{\theta}$ buy both hybrid and inbred line seed and make no profit. As a consequence, the monopolist extracts all of the surplus Π_H from farmers who buy hybrid seed, but incurs a production cost c, and therefore loses $c - \Delta\Pi$ when compared to inbred line seed sold at price Π_L. On the other hand, she shares the surplus from those who buy inbred line seed as a durable good. Overall, the profit of the monopolist is $(c-\Delta\Pi)^2/4\bar{\theta} + 2\Pi_L - (c-\Delta\Pi)$, and for farmers, $(c-\Delta\Pi)^2/8\bar{\theta}$. The total surplus is therefore $3(c-\Delta\Pi)^2/8\bar{\theta} + 2\Pi_L - (c-\Delta\Pi)$.

2.2. Inefficiency of multi-seed monopoly situation

The loss of efficiency as defined by (3) must be compared to $\bar{\theta}/2$. A multi-seed monopolist situation is efficient as

$$\begin{aligned} & \tfrac{(c-\Delta\Pi)^2}{8\bar{\theta}} + (1 - \tfrac{c-\Delta\Pi}{2\bar{\theta}})(c-\Delta\Pi) - \tfrac{\bar{\theta}}{2} \leq 0, \\ \Rightarrow \quad & -3(c-\Delta\Pi)^2 + 8\bar{\theta}(c-\Delta\Pi) - 4\bar{\theta}^2 \leq 0. \end{aligned}$$

We denote $X = c - \Delta\Pi$, and thus, we need to define for what values of X, $-3X^2 + 8\bar{\theta}X - 4\bar{\theta}^2 \leq 0$. This last inequality is satisfied as long as $X \leq 2\bar{\theta}/3$ or $X \geq 2\bar{\theta}$, or equivalently $c \leq \Delta\Pi + 2\bar{\theta}/3$ and $c \geq \Delta\Pi + 2\bar{\theta}$. As the monopolist chooses to produce both seeds if $c \leq \Delta\Pi + 2\bar{\theta}$, it is efficient to introduce hybrid seed as long as $c \leq \Delta\Pi + 2\bar{\theta}/3$.

2.3. Multi-seed monopoly and license fee

The indifferent farmer is now $\tilde{\theta} = 2\Pi_L - \Pi_H - (p_{1L} + \tau) + p_{1H}$ and the monopolist solves

$$\begin{cases} \max\limits_{p_{1L}, p_{1H}} (p_{1L} + \tau) \int_0^{\tilde{\theta}} f(\theta) d\theta + (p_{1H} - c + \Pi_L) \int_{\tilde{\theta}}^{\bar{\theta}} f(\theta) d\theta \\ \text{subject to} \quad \tilde{\theta} = \min\{2\Pi_L - \Pi_H - (p_{1L} + \tau) + p_{1H}, \bar{\theta}\} \\ \qquad\qquad\quad p_{1H} \leq \Pi_H, \\ \qquad\qquad\quad p_{1L} > p_{1H} - \Delta\Pi. \end{cases}$$

If $c < \Delta\Pi + 2\bar{\theta}$ the constraint $0 \leq \tilde{\theta} \leq \bar{\theta}$ is not binding, and the solutions are $p_{1L} = \max\{(3\Pi_L + \Pi_H - c)/2 - \tau, \Pi_L\}$ and $p_{1H} = \Pi_H$. First, if $\tau < \Pi_L - (c - \Delta\Pi)/2$, the optimal inbred line seed price satisfies the last constraint (i.e., $(3\Pi_L + \Pi_H - c)/2 - \tau > p_{1H} - \Delta\Pi$). Second, if $\tau > \Pi_L - (c-\Delta\Pi)/2$, the constraint $p_{1L} \geq p_{1H} - \Delta\Pi$ is binding, so that the optimal inbred line seed price is Π_L.

2.4. Threshold levels Γ_1 and Γ_2

The monopolist's profit if she chooses to produce both seeds in the first period is $(c - \Delta\Pi)^2/4\bar{\theta} + 2\Pi_L - (c - \Delta\Pi)$, whereas her profit if she produces only inbred line seed as a nondurable good is $2\Pi_L - (\Pi_L - \tau)^2/\bar{\theta}$. She chooses to produce both if

$$\begin{aligned} & \tfrac{(c-\Delta\Pi)^2}{4\bar{\theta}} + 2\Pi_L - (c - \Delta\Pi) > 2\Pi_L - \tfrac{(\Pi_L-\tau)^2}{\bar{\theta}}, \\ \Rightarrow \quad & (c - \Delta\Pi)^2 - 4\bar{\theta}(c - \Delta\Pi) + 4(\Pi_L - \tau)^2 > 0. \end{aligned}$$

We denote, as before, $X = c - \Delta\Pi$, and therefore, we need to define the conditions under which $X^2 - 4\bar{\theta}X + 4(\Pi_L - \tau)^2 > 0$. This inequality is satisfied as long as $X < 2\bar{\theta} - 2\sqrt{\bar{\theta}^2 - (\Pi_L - \tau)^2}$ or $X > 2\bar{\theta} + 2\sqrt{\bar{\theta}^2 - (\Pi_L - \tau)^2}$. The last inequality never holds, whereas the first one can be simplified to $c < \Gamma_1 \equiv \Delta\Pi + 2\bar{\theta} - 2\sqrt{\bar{\theta}^2 - (\Pi_L - \tau)^2}$.

The total welfare in the case of a multi-seed monopoly is $3(c - \Delta\Pi)^2/8\bar{\theta} - (c - \Delta\Pi) + 2\Pi_L$, to be compared with the total welfare in the case of a inbred line nondurable good monopoly, namely $2\Pi_L - (\Pi_L - \tau)^2/2\bar{\theta}$. The former is higher than the latter as long as

$$3(c - \Delta\Pi)^2 - 8\bar{\theta}(c - \Delta\Pi) + 4(\Pi_L - \tau)^2 > 0,$$

which is equivalent to $3X^2 - 8\bar{\theta}X + 4(\Pi_L - \tau)^2 > 0$ with $X = c - \Delta\Pi$. The solution to this second degree equation comes down to having $c < \Gamma_2 \equiv \Delta\Pi + 4\bar{\theta}/3 - (4/3)\sqrt{\bar{\theta}^2 - \frac{3}{4}(\Pi_L - \tau)^2}$.

3. Introduction of a license fee in a differentiated duopoly

The introduction of a license fee has no impact on seed prices and market structure. Indeed, it translates the inbred line producer's program to

$$\underset{p_{1L}}{Max}(p_{1L} + \tau) \int_0^{\widetilde{\theta}(\tau)} f(\theta)d\theta + p_{2L}^* \int_{\widetilde{\theta}(\tau)}^{\bar{\theta}} f(\theta)d\theta \tag{7}$$

with $\widetilde{\theta}(\tau) \equiv \min\{p_{1H} - (p_{1L} + \tau) + c - 2\Delta\Pi, \bar{\theta}\}$. In this differentiated market, farmers buy more expensive inbred line seed because they expect to self-produce seed. So the total price they pay is $p_{1L} + \tau \equiv p^\tau$ which goes entirely to the producer. It also determines who buys inbred line seed and self-produces, and who buys seed in both periods. The inbred line producer adapts her pricing strategy accordingly: she reduces p_{1L} when τ increases so as to let $p_{1L} + \tau$ be unchanged. Formally, replacing $p_{1L} + \tau$ with p^τ in the objective function in (7) yields the maximization program (4). Then the inbred line seed producer's best response and equilibrium price can be computed the same way. Hence, the license fee does not increase the efficiency or the inbred line producer's profit in a duopoly competition.

References

[1] "La CVO Recherche Blé Tendre Fonctionne Sereinement," *Semence et Progrès*, *125*:131 (2005).

[2] Alston, Julian M. and Raymond J. Venner. "The effects of the US Plant Variety Protection Act on wheat genetic improvement," *Research Policy*, *31*(4):527–542 (2002).

[3] Bulow, Jeremy I. "Durable-goods monopolists," *Journal of Political Economy*, *90*(2):314–332 (1982).

[4] Bulow, Jeremy I. "An Economic Theory of Planned Obsolescence," *Quarterly Journal of Economics*, *101*(4):729–749 (1986).

[5] Burton, Diana M, et al. "Property rights protection of biotechnology innovations," *Journal of Economics and Management Strategy*, *14*(4):779–812 (2005).

[6] Coase, Ronald. "Durability and monopoly," *Journal of Law and Economics*, *15*(1):143–149 (1972).

[7] European Union. "Council Regulation (EC) No 2100/94 on Community Plant Variety Rights,". http://europa.eu.int/eur-lex/en/consleg/pdf/1994/en_1994R2100_do_001.pdf, 1994.

[8] Gul, Faruk, et al. "Foundations of dynamic monopoly and the Coase conjecture," *Journal of Economic Theory*, *39*(1):155–190 (1986).

[9] Kesan, Jay and Andres A. Gallo. "Insecure property rights and plant varieties: the effect on the market for seeds in Argentina." *American Agricultural Economics Association annual meeting*. 2005.

[10] Lence, Sergio H., et al. "Welfare impacts of intellectual property protection in the seed industry," *American Journal of Agricultural Economics*, *87*(4):951–968 (2005).

[11] Lichtenberg, Erik. "Cost of regulating transgenic pest-protected plants." *Genetically modified pest-protected plants: science and regulation* edited by National Research Council, 217–243, Washington, D.C: National Academy Press, 2000.

[12] Perrin, Richard K. and Lilyan E. Fulginiti. "Dynamic pricing of genetically modified crop traits." *The regulation of agricultural biotechnology* edited by Robert E. Evenson and Vittorio Santaniello, 183–190, CABI, 2004.

[13] van Tongeren, Frank and Derek Eaton. "The case for differentiated appropriability in intellectual property rights for plant varieties." *The Governance of Agricultural Biotechnology* edited by Robert E. Evenson and Vittorio Santaniello, Wallingford, UK: CABI, 2004.

[14] Waldman, Michael. "Planned obsolescence and the R&D decision," *Rand Journal of Economics*, *27*(3):583–595 (1996).

[15] Waldman, Michael. "Durable goods theory for real world markets," *Journal of Economic Perspectives*, *17*(1):131–154 (2003).

Figure 1: Second period surplus sharing with inbred line monopoly, no commitment, and tax (if $\tau \leq \Pi_L - \bar{\theta}$)

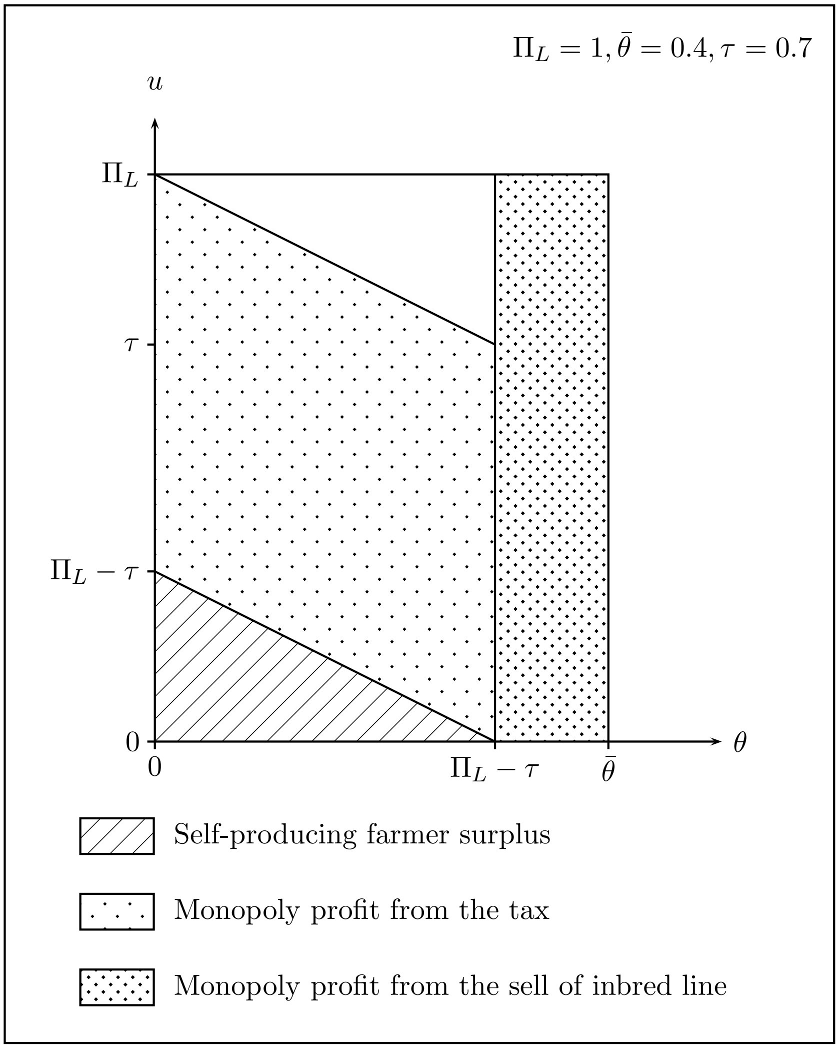


Figure 2: Effect of tax on the monopoly profit and surplus with no commitment

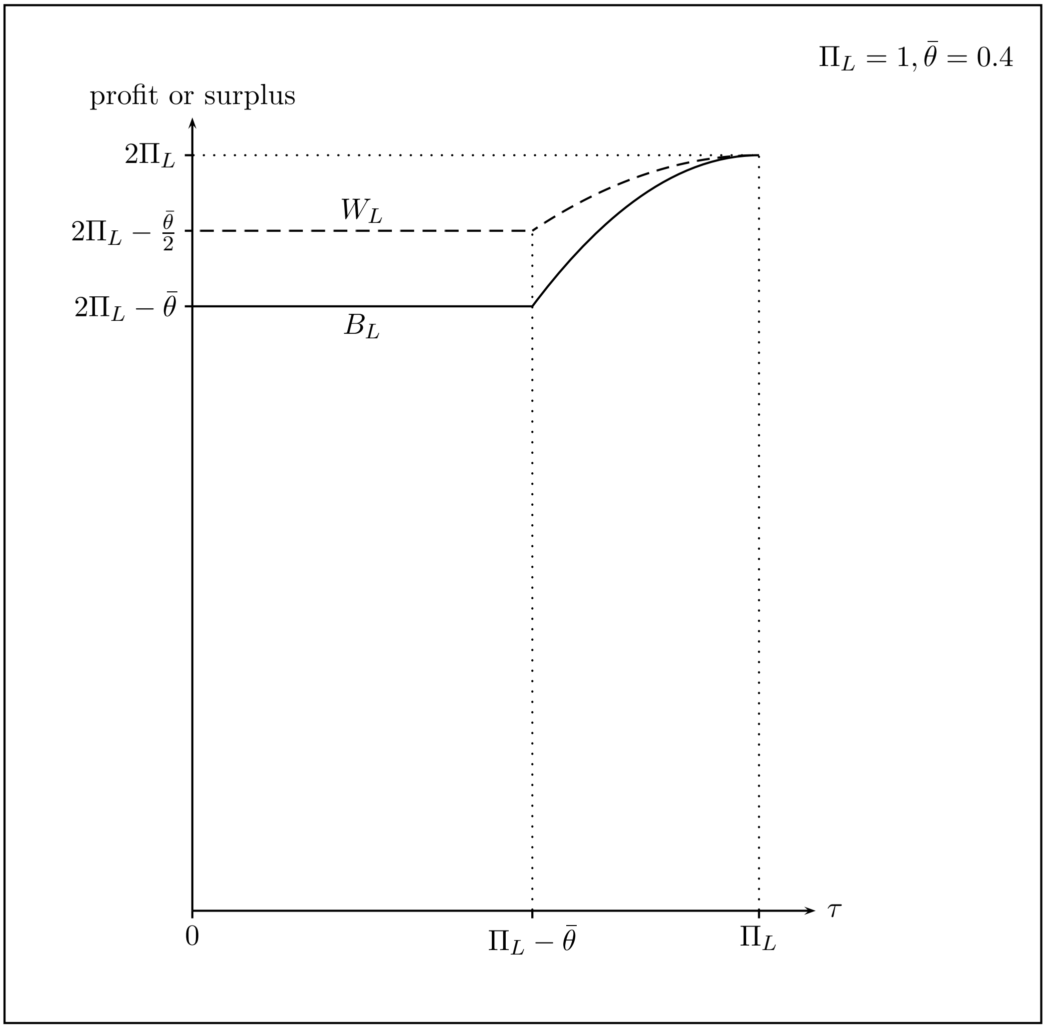


Figure 3: Choice of the type of seed by a mono-seed monopoly with tax (with non commitment when selling inbred only)

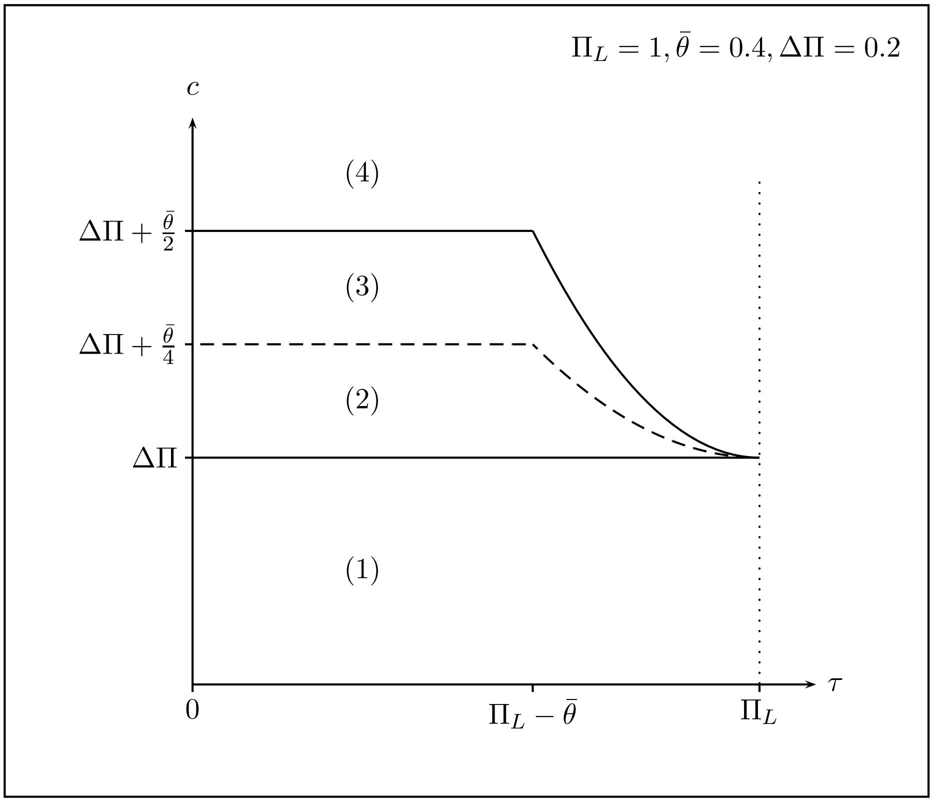


Figure 4: Two periods surplus sharing when the monopoly sells both inbred and hybrid at the period 1 (multiseed monopoly)

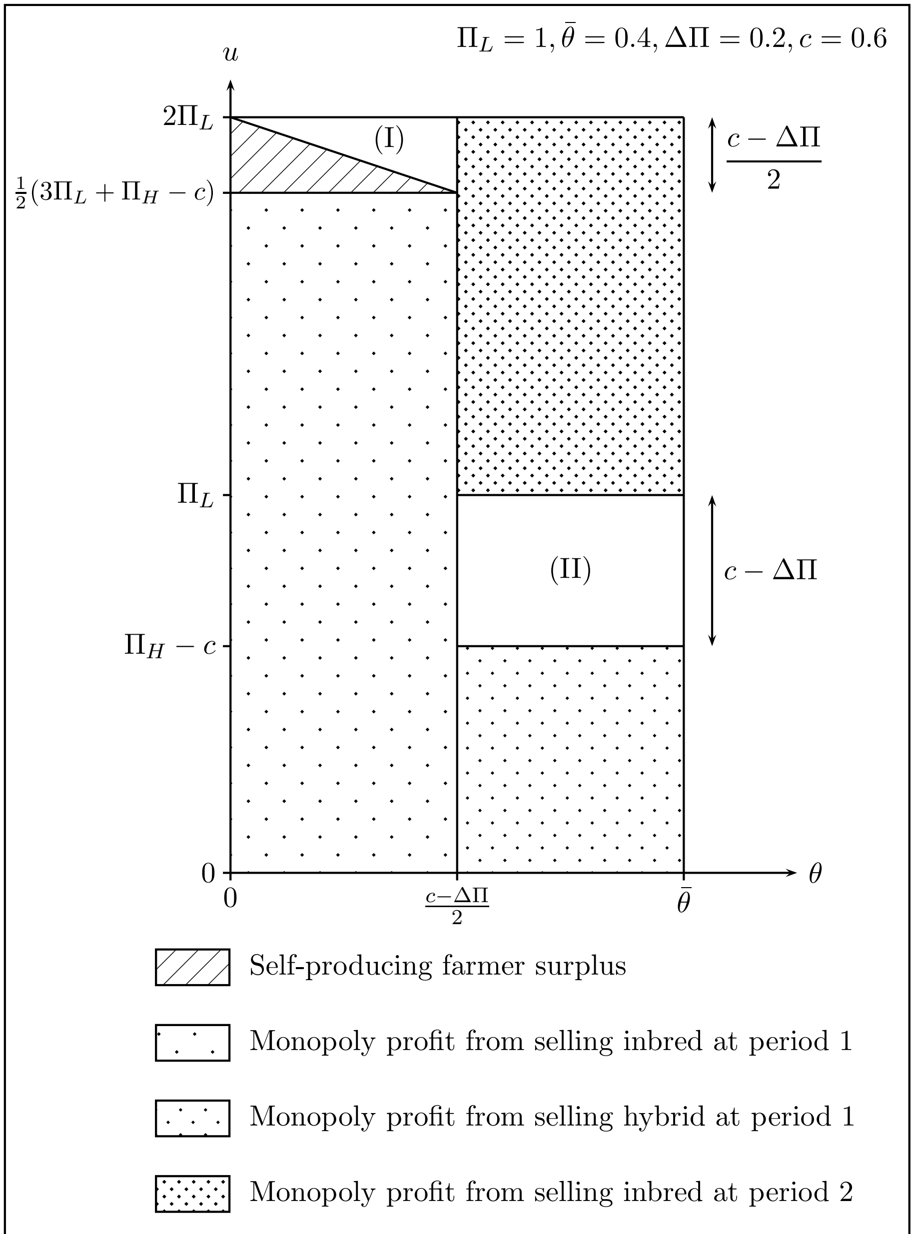
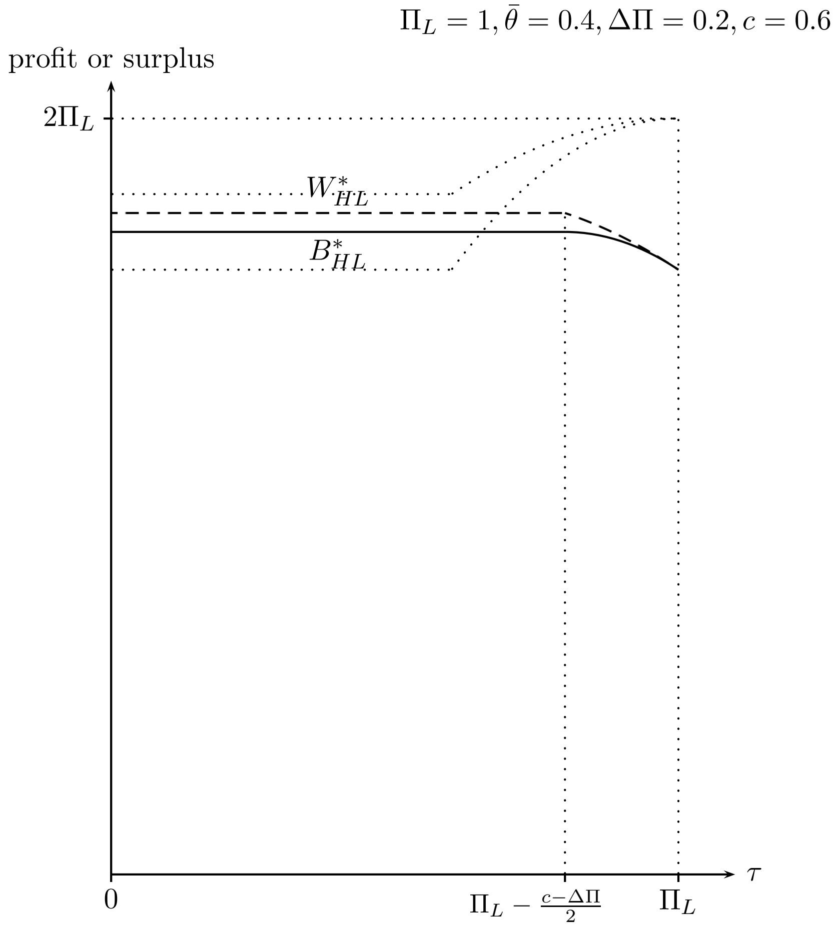


Figure 5: Monopoly profit and surplus with multi-seed monopoly, tax (and no commitment when selling inbred line only)



The dotted curve reminds the curves B_L and W_L given in figure 2.

Figure 6: Choice of the type of seed by a multiseed monopoly with tax (with non commitment when selling inbred only)