Incentive to reduce crop trait durability

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Abstract

Inbred line seed producers face competition from their own consumers: farmers who save part of their harvest can costly self-produce. To reduce this competition, seed producers can switch to non-durable hybrid seed production.

In a two-period model, we investigate what is the impact of crop durability on self-production, pricing strategies and switching decision. We first study the pricing decisions and switching decisions of an inbred line seed monopoly. Then, we analyze how the monopoly's behavior is affected by the entry of a hybrid seed producer. We also examine how the introduction of royalties on farmers who self-produce improves efficiency.

Our main finding is that, for some constellation of costs, an inbred line seed monopoly has an incentive to produce technologically dominated hybrid seed in order to extract more surplus from farmers. Along the same lines, an inbred line monopoly has an incentive to let a hybrid seed producer enters the market for discrimination purposes.

Keywords: Durable good, non-durable good, royalties.
JEL classification: Q16 (R&D and agricultural technology); L12 (Monopoly); L13 (Oligopoly)

1 Introduction

Property rights in the seed sector in Europe and North-America are based on the Plant Breeder's Right (PBR) that allows farmers to use the harvest of one production cycle in order to have some seed for the next production cycle, thereby self-producing seed. Table 1 below shows that the proportion of self-produced seed is important for several crops (e.g., wheat). Farmers buy a particular seed for its own genetic trait properties (e.g., productivity, resistance to insecticide, to pest attack, fitness to a specific climate). When self-producing seeds, farmers produce crop with same trait and they compete with seed dealers on their own demand. In this sense, crop trait can be considered as a durable good.

One way to avoid competition by farmers through seed self-production is to reduce the durability of crop traits. If the quality of the trait decreases dramatically from one generation to the other, self-production becomes unproductive. 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, sunflower during the 1970's, and more recently for canola (with partial success) and wheat (without success). With the recent development of biotechnology, companies have tried to develop some genetical artefacts that make sterile the seed harvested by farmers, such as the controversial "Terminator" seed.

Recently, the regulation in Europe has reformed intellectual property rights (IPRs) in the seed sector by allowing licence fees on crop traits. More precisely, the E.U. directive 2100/94 (article 14) indicates that a producer that self-produces his own seed should pay a royalty fee to the innovator that has 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 not levied or reimbursed if the farmer buys his seed or if he cultivates small surfaces. In accordance with the European directive, a large part of the collected taxes are assigned to the seed company that has created the seed varieties.

We consider a two-period model of crop trait durability. We investigate the impact of crop durability, as well as royalties, on self-production, crop traits, pricing strategies and decisions to reduce crop durability by switching to hybrid seeds. We also examine how royalties on crop traits improve efficiency.

[1] In genetic terms, inbred line seed are homozogous. The consequence is that if an inbred line is self-pollinated, its offspring is genetically homogeneous and identical to the parent inbred line. Hybrid seed are heterozygous and results (generally) from the cross of two different inbred lines. Hybrid seed performance is greater than the performance of the two inbred parental lines. When an 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).

Crop	Seed bought[a]	Type of seed
Corn	100%	100% hybrid
Wheat	20-32%	100% inbred line
Rice	85%	?
Barley	50%	100% inbred line
Oats	40%	100% inbred line
Soybean	76%	100% inbred line
Canola		20% hybrid / 80% inbred line
Sunflower	95%	100% hybrid

[a] proportion of seed bought by the farmers in the US (source: McMullen (1987) reported in Lichtenberg (2000)).

Table 1: Seed markets and seed type in the U.S.

We consider two types of seed: inbred line and hybrid seeds. Farmers can self-produce inbred line seed but not hybrid seed. We assume that farmers are heterogeneous in their seed self-production costs and that seed producers are more efficient in producing seeds than (most) farmers. Self-production is thus sub-optimal but it indeed occurs to compete with powerful (e.g., monopolistic) seed dealers. We also assume that hybrid seed is more costly to produce (by seed producer) but, once planted, it is more productive (for farmers) than inbred line seed. We therefore impose no a priori technological domination of one seed on the other as it will become a main parameter of the model.

We first analyze a monopolistic seed industry where only inbred line seed is produced, whereby the monopoly commits on future prices. 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 non-durable, i.e., the non-durable monopoly profit.

We then assume that the monopoly cannot commit on second-period price. Because farmers make seed self-production decisions before observing seed second-period prices, crop trait durability creates a hold-up problem, which entails efficiency losses as well as a reduction of the monopoly's market power. The monopoly would like to commit to reduce her price in the second period to reduce self-production. However, once farmers have decide not to save part of their harvest to self-produce their seed, they represent a captive demand and thus the monopoly rises her price up to the one-period monopoly pricing. Expecting this behavior, all farmers self-produce their seed, which is inefficient. The introduction of royalty, by making self-production less attractive, increases the efficiency. It also assigns all efficiency gains to the monopoly. When the royalty fee is equal to the one-period monopoly mark-up (i.e., monopoly price net of marginal cost), it allows the monopoly to extract all the surplus.

Second, we investigate the implications of the introduction of hybrid seed in the case of non-commitment on future prices. We first consider that the monopoly cannot produce both inbred line and hybrid seeds, rather she can choose either to switch to hybrid seed production, or keep producing inbred line seed. We show that the monopoly seed producer has an incentive to introduce technological 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, we show that the introduction of royalties reduces the incentive for the monopoly to switch to inefficient hybrid. Yet, the monopoly switches to hybrid when it is efficient to do so only for a royalty fee equals to the one-period monopoly mark-up.

Second, we suppose that the monopoly can produce both inbred line and hybrid seeds. We show that the monopoly sells both technologically dominated hybrid seed and inbred line seed to discriminate among farmers.

Lastly, we introduce duopoly price competition among an inbred line seed producer and a hybrid seed producer. We show that, when hybrid seed is less efficient than inbred line seed, it leads to a differentiated market structure with both types of seed. This equilibrium is inefficient because some farmers self-producer seeds whereas the rest of the farmers use technologically dominated hybrid seeds. A licence fee on self-produced seeds has no impact on the efficiency of the economy nor on the inbred line seed dealer's profit.

It is important to keep in mind that royalties on crop traits are motivated by property rights on innovations. The goal of such a 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 by a non-durable trait. Accordingly, in our paper, we examine the impact of such a regulation not only on the seed dealer's profit, but also on the ex-post efficiency of the entire society.

We restrict ourself to the monopoly and differentiated duopoly cases because intellectual property right favor market power. 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 efficient might require ex-post market power due to strong intellectual property right 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. It is due to the fact that the monopoly cannot commit not to reduce prices in the future to attract the residual demand. The monopoly would like to commit on high prices (e.g., 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 most at marginal cost (Coase, 1972, Bulow, 1982, Gul et al., 1986, Waldman, 2003).

Here, the problem is different. First, the good can be sold during each period as a non-durable good. It is indeed what the monopoly would like to do. She must then commit to set prices low 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 crop are captive demand: they have no choice but to buy again the good. The monopoly is thus tempted to increase her price in the future to hold-up those farmers. Expecting this behavior, all farmers save their harvest and self-produce seed. Thus, 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.

As in the durable good case, the presence of a potential entrant helps the durable good producer to commit on future prices (Ausuble and Deneckere, 1987, Gul, 1987). For durable good, it helps to commit on higher prices and thus restores the monopoly power. Here, it bounds the price upward and thus partly solves the hold-up problem.

Shortening crop traits durability is similar to planned obsolescence of durable goods. Bulow (1986) has formalized the monopoly's incentive to shorten uneconomically the durability of goods in a two-period model. Our framework is different in two points. First, we deal with a good that leaves the option for consumers to make it durable at a cost. The monopoly wants to introduce 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 parameters, the monopoly chooses to produce both types of good to differentiate consumers.

Ozertan et al. (2002) examine the property rights protection of genetic modified (GM) crops in a two-period model. They compare sterile GM seeds with short term and long term contract between the seed producer and the farmers as strategies to protect intellectual property rights. Their focus is mainly on the enforcement and monitoring problems with long term contacts that can be avoided with sterile GM seeds. Here, we abstract for these problems when licence fees are introduced. Rather, we focus on the inefficiency due to the exercise of market power and the self-production of seed. In our model, the choice to introduce non-durable (sterile GM) seed is endogenous, and the monopoly can decide to introduce non-durable seed even though it is less efficient than durable seed.

The paper is organized as follows. The model is exposed in section 2. Section 3 is devoted to the analysis of the inbred line seed monopoly. We first define the pricing strategies when she can commit on future prices, and second in the non-commitment case. We thus investigate how the introduction of a royalty fee affects our findings. Section 4 focuses on the introduction of hybrid seed. We first consider that the monopoly can only switch from inbred line seed production to hybrid seed production. We investigate how this new strategy can alter the monopoly behavior. We then allow for multi-seed production and thus investigate whether the monopoly chooses to produce one or both kinds of seed. In section 5 we analyze a situation in which the monopoly 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. Discount factor is normalized to 1. Each farmer buys zero or one units of seed. One or several seed dealers produce and sell inbred line seeds (L) at a marginal cost normalized to be 0. As the technology becomes available (at no cost), they may also produce and sell hybrid seeds (H) at a higher marginal cost $c > 0$. Farmers get different gross payoffs from buying inbred line seed or hybrid seed, i.e., Π_j with $j = H, L$ where $\Pi_H > \Pi_L$. Thus, hybrid seeds generate higher profit, but are more costly to produce. Yet, we assume that hybrid is worth to be adopted, i.e., $\Pi_H - c > 0$.

Not only the two kinds of seeds have different costs and profits, they also differ in their durability. Unlike hybrid seeds, the inbred line harvest (i.e., the output) can be saved and used to produce seeds for the next period production (as an input). If a farmer buys the 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 cost 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 the analysis we assume that the distribution is uniform and that $\overline{\theta} \leq \Pi_L$.

Since seed dealers have lower seed production costs, seed production by farmers is inefficient. In other words, at the first-best, all seeds are produced by seed dealers. The two-period welfare achieved is thus $2\Pi_L$ with inbred line seed and $2(\Pi_H - c)$ with hybrid seed. Moreover, still at the first-best, hybrid line seed must be adopted whenever $\Pi_H - c \geq \Pi_L$ or, equivalently, $\Pi_H - \Pi_L \equiv \Delta\Pi \geq c$, i.e., the gain of harvest compensates the incremental cost of producing hybrid line seeds.

In our model, the first-best outcome is achieved with perfect competition in the inbred line seed market, even though a monopoly can produce hybrid seeds. Producers set their price at marginal cost 0. Farmers buy during each period, as it would be more costly to self-produce the seed ($\theta \geq 0$). In order to enter the market, a hybrid seed producer has to set her price at $\Delta\Pi$ (such that $\Pi_H - p = \Pi_L$) or possibly just below, i.e., $\Delta\Pi - \varepsilon$. If $\Delta\Pi < c$, the hybrid seed producer does not enter and only inbred line seeds are produced. On the other hand, if $\Delta\Pi \geq c$, entry occurs, and only hybrid seeds are produced. In this latter case, all farmers buy the hybrid line seeds, and the (maximized) total surplus is shared between 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

As a benchmark case, we consider a monopoly that only sells inbred line seeds. We assume first that she can commit in the first period to future prices, and then we investigate the non-commitment case.

3.1 Inbred line monopoly with commitment on second-period price

The monopoly 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 of them decides whether or not to buy the seeds in the first period at price p_{1L} and then each decides whether or not to self-produce for the second period. Those who do not save part of the harvest in the first period, have to decide whether to buy the seeds in the second period at price p_{2L}.

To fully understand the monopoly's pricing strategy, we first consider the case of homogeneous farmers, i.e., when they all have the same cost θ. While committing on a price schedule, the monopoly 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 at period two ("durable good" strategy) or, rather she sells seeds during the two periods ("non durable good" strategy). In the first case, the first-period price is equal to the two-period seed value, namely[2] $p_{1L} = 2\Pi_L - \theta$. The monopoly gets the entire surplus whereas farmers get none of it. However, since seeds are inefficiently self-produced by farmers, the total surplus can be increased if the monopoly sells seeds in the second period. In this case (which is the non durable good strategy), in the second period the monopoly faces farmers' competition, which forces the second-period price to be equal to the farmers' cost, i.e., $p_{2L} = \theta$ (if higher, farmers produce their own seed).

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

In the first period, the monopoly 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 shared between the monopoly who gets $(\Pi_L + \theta)$ and farmers who get $(\Pi_L - \theta)$. Hence, the monopoly has to choose between an inefficient outcome (durable good strategy), where she gets all the surplus, and an efficient one (non-durable good strategy), where she shares the surplus. The choice of the monopoly between the two above pricing strategies depends on the level of the farmers' self-production cost, θ. The monopoly only sells in the first period (respectively, sells during the two periods) when $\theta \leq \frac{\Pi_L}{2}$ (respectively, $\theta \geq \frac{\Pi_L}{2}$).

With heterogeneous farmers, the monopoly 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 non-durable good.

A durable good monopoly sets her prices such as to sell to all the farmers in the first period, and to none of them in the second period. 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 $\widetilde{\theta}$ cost farmer who is indifferent between buying or not, i.e., $\widetilde{\theta} = 2\Pi_L - p_{1L}$ as long as $\widetilde{\theta} \leq \bar{\theta}$. The monopoly's program is thus

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

With $\bar{\theta} \leq \Pi_L$, the solution is a corner solution[3] $p_{1L}^c = 2\Pi_L - \bar{\theta}$. At this price, the monopoly sells to all farmers and gets a payoff of $2\Pi_L - \bar{\theta}$, whereas farmers get a null payoff.

A non-durable good monopoly sells the seeds during the two periods. In the second period, only farmers with high self-production cost will buy the seeds. In this setting, two constraints must be satisfied: the monopoly has to make sure that farmers buy in the first period ($\Pi_L - p_{1L} \geq 0$) and that some farmers will buy in the second period ($\Pi_L - p_{2L} \geq \Pi_L - \theta$). Hence, the non-durable good monopoly program is

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

The optimal prices are therefore

$$\begin{aligned} p_{1L}^c &= \Pi_L, \\ \text{and } p_{2L}^c &= \frac{\bar{\theta}}{2}. \end{aligned}$$

[3] This corner solution is due to the uniform distribution. If most farmers have low θ, the monopoly might prefers to raise prices, thereby excluding farmers with high θ.

With the above pricing schedule, the monopoly sells to all farmers in the first period and only to half of them (i.e., those whose θ is larger than $\frac{\bar{\theta}}{2}$) in the second period. She makes a profit of $\Pi_L + \frac{\bar{\theta}}{4}$ whereas farmers get $\Pi_L - \frac{\bar{\theta}}{4}$.

To summarize, the monopoly can adopt a durable good strategy and gets a payoff of $(2\Pi_L - \bar{\theta})$, or adopt a non-durable good strategy and gets a payoff of $(\Pi_L + \bar{\theta}/4)$. Hence, she has to choose between those two strategies. So long as $\bar{\theta} \geq \frac{4}{5}\Pi_L$, she adopts the non-durable good strategy and thus sells during the two periods.This strategy allows her to extract more surplus, even if there is an inefficiency loss due to self-production in the second period. Indeed, in the second period, the monopoly sells to half of the farmers (those with higher self-production costs) to decrease this inefficiency loss but at a cost of reducing the surplus extracted from those who produce their own seeds (who then gets a positive payoff). On the other hand, as long as $\bar{\theta} < \frac{4}{5}\Pi_L$, she adopts the durable good strategy and thus sells only seeds in the first period. This leads to an inefficient outcome, as all the farmers inefficiently self-produce in the second period.

In the extreme case where $\bar{\theta} = \Pi_L$, the monopoly chooses the non-durable good strategy, and sells seeds during the two periods. Her total two-period payoff is $\frac{5}{4}\Pi_L$. The farmers with high self-producing costs (i.e., $\theta \geq \widetilde{\theta} = \frac{\Pi_L}{2}$) buy the inbred line seed in the second period, whereas the rest of them, with low cost (i.e., $\theta < \widetilde{\theta}$) self-produce their own seed. In the first period, each farmer gets a null payoff, whereas in the second period, each of those who buy seeds gets $\frac{\Pi_L}{2}$, while the others get each $\Pi_L - \theta$. The farmers' total two-period payoff is thus $\int_0^{\widetilde{\theta}} (\Pi_L - \theta) f(\theta) d\theta + \int_{\widetilde{\theta}}^{\bar{\theta}} (\Pi_L - p_{2L}^c) f(\theta) d\theta = \frac{5}{8}\Pi_L$.

3.2 Inbred line monopoly without commitment on second-period price

We now consider that the monopoly cannot commit on future prices. Thus, the timing is the following:

- In the first period, the monopoly sets the first-period price, p_{1L}. The farmers observe the first-period price and each of them decides whether or not to buy inbred line seed. Then, each farmer decides whether or not to save some seed to self-produce in the second period.

- In the second period, the monopoly sets the second-period price, p_{2L}. The farmers observe the price, and each of those who do not self-produce has to decide whether or not to buy the seed.

In absence of any commitment device, we solve the two-period model backward, and we determine the Subgame Perfect equilibrium. Compared to the commitment case, farmers face a hold-up problem. In the second period, the farmers who did not save their harvest to produce their own seed are captive consumers for the seed producer. Therefore, the monopoly can set $p_{2L}^m = \Pi_L$. Expecting that price, none of the farmers buy the second period seed because they are better off if they produce their own seed as $\Pi_L - p_{2L}^m < \Pi_L - \theta$ is always satisfied. Although lower second-period price will induce some farmers not to save and, therefore, to buy from the monopoly in the second period. However, this cannot be an equilibrium as the monopoly will always be tempted to raise her price in the second period up to Π_L, forcing farmers to buy at this price. Anticipating this behavior, all the farmers will save seed in the first period for the second period production. We now turn to the first-period pricing strategy. Given that all farmers self-produce their seed, the monopoly will sell a durable good in the first-period. The first-period price is solution of the following maximization program

$$\underset{p_{1L}}{Max} p_{1L} \int_0^{\tilde{\theta}} f(\theta)d\theta \text{ s.t. } \widetilde{\theta} = \max\{2\Pi_L - p_{1L}, \bar{\theta}\}$$

The solution is still the corner solution $p_{1L}^m = 2\Pi_L - \bar{\theta}$.

Hence, the Subgame Perfect equilibrium is such that the monopoly sells seed as a durable good at price $p_{1L}^m = 2\Pi_L - \bar{\theta}$, and all the farmers save some of the seed from the first period and use it in the second period. None of them buy in the second period at the price $p_{2L}^m = \Pi_L$.

Since farmers inefficiently self-produce seeds, the monopoly outcome is inefficient, and even more inefficient than in the commitment case. This is due to the hold-up problem arising because of the lack of commitment in the second-period price. Now, seeds are self-produced not only by farmers with high cost, but also by those with low cost to avoid to be captive and, therefore, they have not choice but to buy at price Π_L. Both seed producer and farmers are worse off because of this hold-up/commitment problem.

Remark 1 Notice that the decrease from the first-period price to the second-period price is not due to the standard durable good commitment problem but rather to the hold-up problem. Indeed, here, the monopoly is tempted to increase her second-period price because the demand she faces is captive, whereas in the standard durable good/Coase problem, she is tempted to decrease it to serve more consumers.

Remark 2 The case where the monopoly cannot commit on prices but farmers observe prices before deciding whether to self-produce seed or not is equivalent to the commitment case.

Remark 3 Notice also that, in reality, new farmers enter the market in each period. In our setting, new farmers should enter during each period so that prices are $2\Pi_L - \bar{\theta}$ in every period and farmers buy every two periods. Maybe it is worth to extend the model to an infinity of periods with half of the farmers entering during each period.

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

3.3 Monopoly pricing strategy with royalties

We now investigate the impact of a given royalty fee τ paid by farmers that produce their own seed on the pricing strategy of the monopoly. We assume that $0 < \tau \leq \Pi_L$.

If the monopoly chooses the durable good strategy, the imposition of a royalty fee does not change our findings. Indeed, the monopoly simply accounts for the royalty 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 royalty fee makes self-production more costly, and thus makes the non-durable good strategy more attractive for the monopoly. To see that, consider the case of non-commitment on second period price. As before, the lack of commitment implies that the second-period price will be the highest possible, namely $p_{2L}^m = \Pi_L$. Expecting this price and with the imposition of royalties, some farmers will not self-produce seeds. Figure 1 illustrates this result.

Insert figure 1

Farmers with low production cost (i.e., $\theta < \Pi_L - \tau$) still prefer to self-produce, and they only earn $(\Pi_L - \tau - \theta)$, where τ is transferred to the monopoly in the second period. Farmers with high self-production cost earn a negative profit by self-producing, and consequently prefer to earn no profit and buy seed in the second period at price $p_{2L} = \Pi_L$. Note that some farmers prefer to buy seed only if the royalty level is high enough (i.e., $\tau > \Pi_L - \bar{\theta}$), which is always true for $\bar{\theta} = \Pi_L$. When choosing the non-durable good strategy, the monopoly earns Π_L in the first period and, using figure 1, we can see that her two-period payoff is $2\Pi_L - \frac{(\Pi_L - \tau)^2}{\bar{\theta}}$.

Comparing the two strategies, the monopoly prefers to sell seed as a non-durable good as soon as some farmers are willing to buy seed at second-period price $p_{2L} = \Pi_L$ (i.e., when $\tau > \Pi_L - \bar{\theta}$). When this condition is fulfilled, the monopoly earns more from the farmers who self-produce and from those who do not.[4] Note also that this choice leads to an increase in the total surplus,

[4] Consider first the farmer who self-produces in both cases. For each unit, the monopoly earns $2\Pi_L - \bar{\theta} - \tau + \tau$ if she sells as a durable good, and $\Pi_L + \tau$ if she sells as a non-durable good. In the former case, the monopoly decreases her price when the royalty fee increases, but not in the second case. Hence, the profit is greater in the second case when the royalty level is high enough ($\tau > \Pi_L - \bar{\theta}$). Consider now the farmer who buys seed in the second period when the seed is sold as a non-durable good. For each unit the monopoly still earns $2\Pi_L - \bar{\theta}$ in the first case, and earns the full surplus $2\Pi_L$ in the latter case.

since inefficient farmers with high self-production cost buy seed that is efficiently produced. The increase in the monopoly profit is greater than the increase in the surplus because the monopoly gets all the increase in surplus, plus the gain from the increased tax from self-producing farmers. In the extreme case where $\tau = \Pi_L$, the monopoly extracts all the surplus. Only farmers with null production costs self-produce and pay royalties. All the other farmers buy seed during each period at the one-period monopoly price Π_L.

To sum-up (see figure 2), when $\tau \in (0, \Pi_L - \bar{\theta}]$, the monopoly sells seed only in the first period (as a durable good) at price $2\Pi_L - \bar{\theta} - \tau$ and makes a profit of $2\Pi_L - \bar{\theta}$. The farmers get a surplus $\frac{\bar{\theta}}{2}$ and the total surplus is thus $2\Pi_L - \frac{\bar{\theta}}{2}$. With a royalty fee $\tau \in [\Pi_L - \bar{\theta}, \Pi_L]$, the monopoly sells seed during both periods at prices $p_{1L}^m = p_{2L}^m = \Pi_L$. Farmers get a total surplus equal to what they save by self-producing, formally $\int_0^{\tilde{\theta}} \Pi_L - (\theta + \tau) d\theta = \frac{1}{2\bar{\theta}}(\Pi_L - \tau)^2$. The total surplus (i.e., the sum of farmers and seed producer surplus) is then $2\Pi_L - \frac{1}{2\bar{\theta}}(\Pi_L - \tau)^2$. The inefficiency loss due to self-production is $\int_0^{\tilde{\theta}} \theta d\theta = \frac{1}{2\bar{\theta}}(\Pi_L - \tau)^2$.

Insert figure 2

We sum up the previous analysis in the following proposition:

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

Remark 4 If royalties 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 which intends to provide the seed producer a return on her investment in R&D, such a redistribution might be more acceptable from the farmers' point of view.

4 Introduction of hybrid seed

Suppose now that the hybrid seed becomes available exclusively to the monopoly at constant marginal production cost $c > 0$. Let p_{tj} denote the price charged in period $t = 1, 2$ for seed $j = H, L$ (if sold). Each farmer has to decide which seed to buy. If he buys hybrid seed in the first period, he cannot use part of his first-period harvest to produce seed for the second-period. He has to buy either the inbred line at price p_{2L} or the hybrid seed at price p_{2H} to produce in the second period.

In this setting, we investigate under what circumstances the monopoly 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 monopoly can only produce one kind of seed (hybrid or inbred line) e.g., for technological, legal and/or marketing reasons. We then allow the monopoly to sell both seeds.

4.1 Switching from inbred line seed to hybrid seed

We consider first that the monopoly can only produce one type of seed: either inbred line seed or hybrid seed. If the monopoly introduces hybrid seed in the first period, she behaves as a non-durable good monopoly and thus sets the monopoly price in each period, i.e., $p_{1H}^m = p_{2H}^m = \Pi_H$. None of the farmers can use their seed for the next period, and they all buy seeds at their valuation, Π_H. The two-period benefit of the monopoly is thus $2(\Pi_H - c)$ whereas farmers get a null benefit. If the monopoly keeps producing inbred line seed, so long as $\bar{\theta} \geq \frac{4}{5}\Pi_L$ (respectively, $\bar{\theta} < \frac{4}{5}\Pi_L$), she adopts the non-durable good strategy (respectively, the durable good strategy) and gets a two-period payoff of $\Pi_L + \frac{\bar{\theta}}{4}$ (respectively, $2\Pi_L - \bar{\theta}$).

Thus, so long as $\bar{\theta} < \frac{4}{5}\Pi_L$ (respectively, $\bar{\theta} \geq \frac{4}{5}\Pi_L$) she switches to hybrid seed production in the first period[5] if $c \leq \Delta\Pi + \frac{\bar{\theta}}{2}$ (respectively, $c \leq \Delta\Pi + \frac{1}{2}\Pi_L - \frac{\bar{\theta}}{8}$).

However, from a social viewpoint, hybrid should be produced only if $c < \Delta\Pi + \frac{\bar{\theta}}{4}$ for $\bar{\theta} \leq \frac{4}{5}\Pi_L$ or if $c < \Delta\Pi$ for $\bar{\theta} > \frac{4}{5}\Pi_L$.

If $\bar{\theta} < \frac{4}{5}\Pi_L$, four areas can be defined depending on the value of c (see Figure 3). (1) If $c < \Delta\Pi$ the monopoly switches to hybrid seed production, which is also the most efficient technology (first-best choice). (2) If $c \in [\Delta\Pi, \Delta\Pi + \frac{\bar{\theta}}{4}]$, the dominated hybrid seed is produced by the monopoly. This is because, even if it is less efficient, by avoiding self-production, hybrid technology allows her to extract all the surplus. This switch is efficient (i.e., leads to higher surplus compared to inbred line seed) in a monopoly framework because the price schedule with inbred line seed leads farmers to inefficiently self-produce seed. (3) If $c \in [\Delta\Pi + \frac{\bar{\theta}}{4}, \Delta\Pi + \frac{\bar{\theta}}{2}]$, the dominated hybrid seed is still produced by the monopoly, for the same reason that in zone (2). However, this switch is inefficient because hybrid seed production is becoming excessively inefficient even if it avoids inefficient self-production. (4) If $c > \Delta\Pi + \frac{\bar{\theta}}{2}$, the monopoly keeps producing inbred line seed, which corresponds to an efficient choice.

[5] We can think of a situation where the monopoly switches to hybrid seed production only in the second period (i.e., while producing inbred line seed in the first period). However this strategy is obviously dominated for the seed producer viewpoint.

Insert figure 3

We sum up this result in the following proposition:

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

If $\bar{\theta} \geq \frac{4}{5}\Pi_L$, there exist only three different areas. As before, if $c < \Delta\Pi$, the monopoly efficiently switches to hybrid seed production. If $c \in [\Delta\Pi, \Delta\Pi + \frac{1}{2}\Pi_L - \frac{\bar{\theta}}{8}]$, the monopoly inefficiently switches to hybrid seed production. Finally, if $c > \Delta\Pi + \frac{1}{2}\Pi_L - \frac{\bar{\theta}}{8}$, the monopoly does not switch to hybrid seed production as it is too expensive to do so. Thus, in this case, for intermediate values of the marginal cost (i.e., $c \in [\Delta\Pi, \Delta\Pi + \frac{1}{2}\Pi_L - \frac{\bar{\theta}}{8}]$), the monopoly always switches inefficiently.

We now investigate whether royalties can provide to the monopoly with incentives to switch to hybrid seed production when it is efficient to do so in the case where $\bar{\theta} \leq \frac{4}{5}\Pi_L$. Figure 3 represents how the four zones described earlier are affected by the royalty level. When $\tau \in (0, \Pi_L - \bar{\theta}]$, we already know that the royalty has no effect on the monopoly equilibrium, including prices, profits and welfare. Thus, a royalty fee τ cannot give incentives to switch to hybrid seed production. For $\tau \in [\Pi_L - \bar{\theta}, \Pi_L]$, the monopoly profit and the total welfare depends on τ. The monopoly switches to hybrid when $c \leq \Delta\Pi + \frac{(\Pi_L - \tau)^2}{2\bar{\theta}}$ (zones 1, 2 and 3) whereas it is efficient to switch for $c \leq \Delta\Pi + \frac{(\Pi_L - \tau)^2}{4\bar{\theta}}$ (zones 1 and 2). The "inefficiency zone", $[\Delta\Pi + \frac{(\Pi_L - \tau)^2}{4\bar{\theta}}, \Delta\Pi + \frac{(\Pi_L - \tau)^2}{2\bar{\theta}}]$ (zone 3) in which the monopoly switches to hybrid although it is efficient to keep producing inbred line seed with monopoly pricing, shrinks as τ increases. This is because higher royalty fee increases the profit of the inbred line seed monopoly, and, therefore, makes the switch to dominated hybrid seed less attractive. Yet, this inefficiency zone exists as long as $\tau < \Pi_L$, meaning that imposing royalty does not always provide with incentives to efficiently switch. The monopoly switches at the efficient threshold 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 monopoly gets all the surplus from inbred line seed production.

Proposition 3 *Royalty makes the monopoly switch inefficiently to hybrid less often. She always switches efficiently only when the royalty allows her to capture all surplus with inbred line seeds, i.e., $\tau = \Pi_L$.*

4.2 Multi-seed production

We now analyze the case where the monopoly can sell both types of seeds.

Suppose first that hybrid seed is more efficient than inbred line seed (i.e., $c < \Delta\Pi$). The monopoly has thus no incentive to sell both types of seed. Hybrid seed has two advantages: it enables to have a higher profit because of higher efficiency, and it enables to extract all the surplus because it is non-durable in the sense that farmers are captive demand in the second-period. The monopoly charges prices $p_{1H} = p_{2H} = \Pi_H$ and therefore earns $2(\Pi_H - c)$.

Conversely, assume that inbred line seed is more efficient than hybrid seed (i.e., $c > \Delta\Pi$). In the second period, the monopoly sells only inbred line seed at price $p_{2L} = \Pi_L$, which yields a payoff Π_L that is greater than $\Pi_H - c$. In the first period, the picture is more complex. For given first-period prices of the two seeds, farmers with low self-production cost θ buy inbred line seed and self-produce seed[6] whereas those with high θ buy hybrid in the first period and inbred line seed at 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, the monopoly solves

$$\begin{aligned}
\max_{p_{1L},p_{1H}} \; & p_{1L} \int_0^{\tilde{\theta}} f(\theta)d\theta + (p_{1H} - c + \Pi_L) \int_{\tilde{\theta}}^{\bar{\theta}} f(\theta)d\theta \\
\text{s.t} \quad & \tilde{\theta} = 2\Pi_L - \Pi_H - p_{1L} + p_{1H}, \\
& 0 \leq \tilde{\theta} \leq \bar{\theta}, \\
& p_{1H} \leq \Pi_H, \\
& p_{1L} > p_{1H} - \Delta\Pi.
\end{aligned}$$

The last constraint means that no farmer buys inbred line seed instead of hybrid seed in the first period, for a one period use only.

The objective function simplifies 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 maximize the objective function on $\tilde{\theta}$ instead of p_{1L}, so that the program of the monopoly becomes

$$\begin{aligned}
\max_{\tilde{\theta},p_{1H}} \; & \frac{1}{\bar{\theta}}\left[\bar{\theta}(p_{1H} + \Pi_L - c) + \tilde{\theta}(\Pi_L - \Pi_H + c - \tilde{\theta})\right] \\
\text{s.t} \quad & \tilde{\theta} = 2\Pi_L - \Pi_H - p_{1L} + p_{1H}, \\
& 0 \leq \tilde{\theta} \leq \bar{\theta}, \\
& p_{1H} \leq \Pi_H, \\
& p_{1L} > p_{1H} - \Delta\Pi.
\end{aligned}$$

The solutions are $p_{1H} = \Pi_H$ and $\tilde{\theta} = \min\{\frac{1}{2}(c-\Delta\Pi), \bar{\theta}\}$. If $\frac{1}{2}(c-\Delta\Pi) < \bar{\theta}$, the upward constraint on $\tilde{\theta}$ is not binding and therefore $p_{1L} = \frac{1}{2}(3\Pi_L+\Pi_H-c)$. Otherwise, if $\frac{1}{2}(c-\Delta\Pi) \geq \bar{\theta}$, it is binding

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

and thus the monopoly sells only inbred line seed in the first period at price $p_{1L} = 2\Pi_L - \bar{\theta}$.[7]

To summarize, the monopoly adopts the following pricing strategies. When $\Delta\Pi < c < \Delta\Pi + 2\bar{\theta}$, she sells both inbred line and hybrid seeds at respective prices $p_{1L} = \frac{1}{2}(3\Pi_L + \Pi_H - c)$ 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 seed production cost $\theta \leq \tilde{\theta} = \frac{1}{2}(c - \Delta\Pi)$ buy inbred line seed in the first period and produce their own seed for 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 monopoly sells only inbred line seed at prices $p_{1L} = 2\Pi_L - \bar{\theta}$ and $p_{2L} = \Pi_L$.

With a multi-seed monopoly, farmers $\theta \leq \tilde{\theta} = \frac{c-\Delta\Pi}{2}$ get a surplus $\tilde{\theta} - \theta$ by buying inbred line seed and self-producing, whereas farmers $\theta \geq \tilde{\theta}$ buy both hybrid and inbred line seeds and make no profit. As a consequence, the monopoly extracts all the surplus Π_H from farmers who buy hybrid seed but incurs production cost c and therefore loses $c - \Delta\Pi$ when comparing with inbred line seed sold at price Π_L. On the other hand, she shares surplus on those who buy inbred line seed as a durable good.

Figure 4 is helpful to understand the gain and loss from the multi-seed strategy.

Insert figure 4

The total loss of welfare compared to the first-best outcome with only inbred line seed and no self-production is

$$\frac{(c - \Delta\Pi)^2}{8\bar{\theta}} + \left(1 - \frac{c - \Delta\Pi}{2\bar{\theta}}\right)(c - \Delta\Pi)$$

The first term represents the efficiency loss due to self-production (zone I in figure 4) whereas the second term represents the efficiency loss due to the use of the inefficient hybrid seed (zone II in figure 4). Furthermore, the above loss must be compared to the inefficiency loss due to self-production from all farmers, formally $\frac{\bar{\theta}}{2}$. We conclude that it is efficient to introduce hybrid seed in a monopolistic industry when $c \leq \Delta\Pi + \frac{2\bar{\theta}}{3}$. This leads to the following proposition.

Proposition 4 *When the monopoly 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* $c \leq \Delta\Pi + \frac{2\bar{\theta}}{3}$.

Even if inbred line seed is more efficient, the monopoly can extract more surplus by also selling hybrid seed. This is because when she produces only inbred line seed, she serves all the

[7]Note that since, by assumption, $c - \Delta\Pi > 0$, the downward constraint on $\tilde{\theta}$ is never binding.

demand.[8] She thus has to match her price with the willingness to pay for a durable good of the less efficient farmers $\bar{\theta}$. With hybrid seed, she can discriminate farmers by serving the less efficient ones (i.e., those with high θ) with hybrid seed, thereby increasing price for the more efficient ones (i.e., those with low θ). Hence, she increases the rent extracted from the more efficient farmers.

Remark 5 Notice that if $\bar{\theta} \geq \frac{\Pi_L}{2}$, then the monopoly always produces both seeds when hybrid seed is dominated. This is because $\bar{\theta} \geq \frac{\Pi_L}{2}$ is equivalent to $\Pi_H \leq \Delta\Pi + 2\bar{\theta}$ and, since $c \leq \Pi_H$, it implies that $c \leq \Delta\Pi + 2\bar{\theta}$. Indeed, $\Pi_H \geq \Delta\Pi + 2\bar{\theta}$ simplifies to $\bar{\theta} \geq \frac{\Pi_L}{2}$.

Remark 6 By comparing results 2 and 4, we find that if $c \in [\Delta\Pi, \Delta\Pi + 2\bar{\theta}]$, selling both hybrid and inbred line seeds at period 1 enables to increase the monopoly profit compared to the case where only one type of seed is sold.

We now investigate the effect of royalties on the decision to introduce hybrid seed. We first derive the optimal monopoly profit with royalty when the monopoly sells both hybrid and inbred line seeds. We then compare this profit level with the profit level when only inbred line seed are produced.

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

$$\begin{aligned}
&\max_{p_{1L},p_{1H}} (p_{1L} + \tau) \int_0^{\tilde{\theta}} f(\theta)d\theta + (p_{1H} - c + \Pi_L) \int_{\tilde{\theta}}^{\bar{\theta}} f(\theta)d\theta \\
&\text{s.t.}\tilde{\theta} = 2\Pi_L - \Pi_H - (p_{1L} + \tau) + p_{1H}, \\
&0 \leq \tilde{\theta} \leq \bar{\theta}, \\
&p_{1H} \leq \Pi_H, \\
&p_{1L} > p_{1H} - \Delta\Pi.
\end{aligned}$$

We focus here on the case where c is low enough ($c < \Delta\Pi + 2\bar{\theta}$) so that the constraint $0 \leq \tilde{\theta} \leq \bar{\theta}$ is not binding. The solutions are $p_{1L} = \max\{\frac{1}{2}(3\Pi_L + \Pi_H - c) - \tau, \Pi_L\}$ and $p_{1H} = \Pi_H$. If $\tau < \Pi_L - \frac{c-\Pi_H}{2}$, the optimal inbred line seed price satisfies the last constraint (i.e., $\frac{1}{2}(3\Pi_L + \Pi_H - c) > p_{1H} - \Delta\Pi$). The monopoly profit is not affected by the royalty fee because the monopoly decreases the price charged to self-producing farmers by the same amount that the royalty fee she gets from these farmers after they buy the seed. If $\tau > \Pi_L - \frac{c-\Pi_H}{2}$, the constraint $p_{1L} > p_{1H} - \Delta\Pi$ is binding, so that the optimal inbred line seed price is Π_L. The monopoly does not use hybrid seed as a discrimination device any longer because she can extract a larger part of the self-producing farmers' profit with the high tax level.[9] Note that the equilibrium is then identical to the one we got earlier with a mono seed monopoly (cf. section 3.3.).

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

[9] If the monopoly chooses to sell hybrid seed, she would then choose p_{1L} slightly higher than Π_L. Only farmers with $\theta \leq \Pi_L - \tau$ would self produce. The monopoly profit would be decreasing with τ as shown in figure 5.

We now analyze how royalties affect incentives to produce both hybrid and inbred line seed in the first period, instead of selling only inbred line seed. This comparison is made for low enough values of c ($c < \Delta\Pi + 2\bar{\theta}$) so that there is a potential interest for using hybrid seed.[10] When selling both hybrid and inbred line seeds, we need to distinguish two cases depending on the value of the royalty fee with respect to $\Pi_L - \frac{c-\Pi_H}{2}$. When selling only inbred line seed, two cases are possible depending on the value of the royalty fee with respect to $\Pi_L - \bar{\theta}$. If $c < \Delta\Pi + 2\bar{\theta}$, we have $\Pi_L - \bar{\theta} < \Pi_L - \frac{c-\Pi_H}{2}$, so that three cases need to be considered:

- If $\tau < \Pi_L - \bar{\theta}$, the royalty does not affect the monopoly profit and the surplus with any strategy (hybrid and inbred line seeds or only inbred line seed). The results are identical to those obtained earlier with no royalty (see proposition 4).

- If $\tau \in [\Pi_L - \bar{\theta}, \Pi_L - \frac{c-\Delta\Pi}{2}]$, the royalty affects the monopoly profit and the surplus when only inbred line seed is produced. The monopoly prefers to sell both hybrid and inbred line seed in the first period if

$$c < \Delta\Pi + 2\bar{\theta} - \sqrt{\bar{\theta}^2 - (\Pi_L - \tau)^2}.$$

  A comparison of the surplus enables us to show that surplus increases when both hybrid and inbred line seeds are sold at the first period if

$$c < \Delta\Pi + \frac{4}{3}\bar{\theta} - \frac{2}{3}\sqrt{\bar{\theta}^2 - \frac{3}{4}(\Pi_L - \tau)^2}.$$

- If $\tau > \Pi_L - \frac{c-\Delta\Pi}{2}$, the monopoly no longer chooses to produce both hybrid and inbred line seeds in the first period. However, we need also to consider that case where the monopoly chooses to sell hybrid seed during the two periods. This trade-off between selling only inbred line seed or only hybrid seed as been studied earlier, and we have shown that the monopoly earns more by selling hybrid seed only if c is not too high (see results 2 and 3).

Figure 6 provides a synthetic representation of these three cases.

Insert figure 6

This strategy leads to a lower profit than the one the monopoly gets by choosing p_{1L} slightly lower than Π_L and producing only inbred line seed in the first period.

[10] If $c > \Delta\Pi + 2\bar{\theta}$ and there is no royalty, we have seen that the multi-seed monopoly prefers not to sell hybrid seed and sell only inbred line seed as a durable good ($p_{1L} = 2\Pi_L - \bar{\theta}$). The situation is identical to the one we studied before with a monopoly selling only inbred line seed. With a royalty and such high values of c, we have seen that the monopoly will still prefer to sell inbred line seed.

The arguments for areas (1) to (4) are identical to those provided for figure 3. Hence, when $\tau > \Pi_L - \frac{c-\Delta\Pi}{2}$, we come back to the comparison of the mono-seed monopoly: this part of figure 6 is identical to figure 3.

Proposition 5 *Royalties makes the monopoly switches inefficiently to hybrid less often. She always switches efficiently only when the royalty allows her to capture all surplus with inbred line seeds, i.e.* $\tau = \Pi_L$.

5 Differentiated duopoly

We push further our investigation, and consider the case where the monopoly only produces inbred line seed, and a potential entrant can produce hybrid seed. This may be due to the fact that the inbred line producer cannot produce the hybrid seed (e.g., for technical or legal reasons), but another producer can do it. In this setting, the two producers compete with different seeds. Each seed producer sets her price p_{tj} in each period $t = 1, 2$ for $j = H, L$. Prices are chosen simultaneously.

Pricing strategies are different once competition is introduced. In this new setting we investigate whether technologically dominated seed is still introduced, why and how it affects efficiency. We also examine the impact of a licence fee on self-produced seed.

First, it is easy to show that if hybrid seed production is a better technology, i.e., $c < \Delta\Pi$, only the hybrid producer survives in the market. In the second period, the hybrid producer sets a price such that the inbred line producer is excluded from the market. Indeed, if $p^*_{2H} = \Delta\Pi - \varepsilon$, farmers only buy from the hybrid producer in the second period, i.e., $\Pi_H - p^*_{2H} > \Pi_L - p_{2L}$ for any price $p_{2L} > 0$. On the other hand, farmers never self-produce seed as $\Pi_H - p^*_{2H} > \Pi_L - \theta$ is always satisfied for any $\theta > 0$. In the first period, the hybrid producer sets the same price $p^*_{1H} = \Delta\Pi - \varepsilon$ and thus gets all the demand. In this case, only hybrid seeds are produced and farmers cannot produce seeds.

Second, consider the case where both seeds are as efficient for one period, i.e., $c = \Delta\Pi$. In the second period, seed producers are in a one-period Bertrand competition with heterogenous products. Prices are set to $p_{2L} = 0$ and $p_{2H} = c$. Producers share the second-period demand. Expecting those prices, no farmer self-produce seed since self-production costs exceed seed prices. Therefore, all farmers buy seed as non-durable good in the first period. Seed producers are thus also in an one-period Bertrand competition in the first period. They set their prices at $p_{2L} = 0$ and $p_{2H} = c$ and share the total demand.

If both seeds are as efficient, the competition is so hard that prices match firms' seed production costs. As a consequence, no farmer self-produce seeds. Firms are in a Bertrand competition in each period.

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

In the first period, seed producers are engaged in a price competition with differentiated seeds, one being with durable genetic trait. Farmers rank seeds according to their self-production costs: those with low θ have a higher willingness to pay for the durable seed. Inbred line seed producer targets farmers with low θ who then self-produce seed whereas hybrid producer sells to those with high θ who buy seeds during each period. Formally, with first-period prices, 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

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

When choosing her first-period price, the inbred line seed producer trade-offs first period profits with the second period ones. By fixing lower first period prices, she attracts more consumers in the first period who are willing to self-produce seeds. 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}

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

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

$$p_{1H} = \frac{\bar{\theta} + p_{1L}}{2} + \Delta\Pi. \tag{3}$$

The two above best responses (2 and 3) yield a unique Nash equilibrium (p^e_{1L}, p^e_{1H}) defined as

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

Prices (p^e_{1L}, p^e_{1H}) are the equilibrium prices when selling at price p^e_{1H} is profitable for the hybrid seed producer, that is when p^e_{1H} is higher than marginal cost c. In the opposite case $p^e_{1H} < c$, meaning that $c > \Delta\Pi + 2\bar{\theta}$, then the hybrid seed producer has no choice but to charge at marginal cost $p^c_{1H} = c$ whereas the inbred line seed producer chooses her best response to this price, $p^c_{1L} = \frac{3}{2}(c - \Delta\Pi)$. 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 sum-up, when $\Delta\Pi < c \leq \Delta\Pi + 2\bar{\theta}$, seed producers compete in price in a differentiated market. Farmers with low seed production costs buy inbred line seed in the first period and self-produce seed for the second period. Farmers with high 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 farmers who then self-produce seed.

In any case, duopoly pricing leads to inefficient seed self-production by farmers as long as $c > \Delta\Pi$. Moreover, farmers who do not self-produce seed buy technologically dominated hybrid seed which is also inefficient. Thus if $c > \Delta\Pi$, the presence of hybrid seed reduces self-production but to the detriment of 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. It thus mitigates the hold-up problem highlighted in the monopoly inbred line with no commitment case to the benefit of the inbred line producer.

Now, what is the impact of a royalty fee on seed self-production in this duopoly equilibrium? It is easy to show that a licence fee $\tau > 0$ has no impact on seed prices and market structure. Indeed, it translates the inbred line producer's program to

$$\underset{p_{1L}}{Max}(p_{1L} + \tau) \int_0^{\widetilde{\theta}(\tau)} f(\theta)d\theta + p^*_{2L} \int_{\widetilde{\theta}(\tau)}^{\bar{\theta}} f(\theta)d\theta \qquad (4)$$

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 that the total price they pay is $p_{1L} + \tau \equiv p^\tau$. This amount goes into the producer's pocket. 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 to let $p_{1L} + \tau$ be unchanged. Formally, replacing $p_{1L} + \tau$ by p^τ in the objective function in (4) yields the maximization program (1). Then the inbred line seed producer's best response and equilibrium price can be computed the same way. Hence, the licence fee does not increase the efficiency nor the inbred line producer's profit in a duopoly competition.

Proposition 6 *When* $\Delta\Pi + 2\bar{\theta} \geq c > \Delta\Pi$, *in a duopoly competition, the inbred line seed producer sells her product 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 non-durable good. This differentiated market structure is inefficient because self-produced seeds as well as hybrid seeds are technologically dominated. A licence fee on self-produced seeds has no impact on the market equilibrium and, therefore on its efficiency.*

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

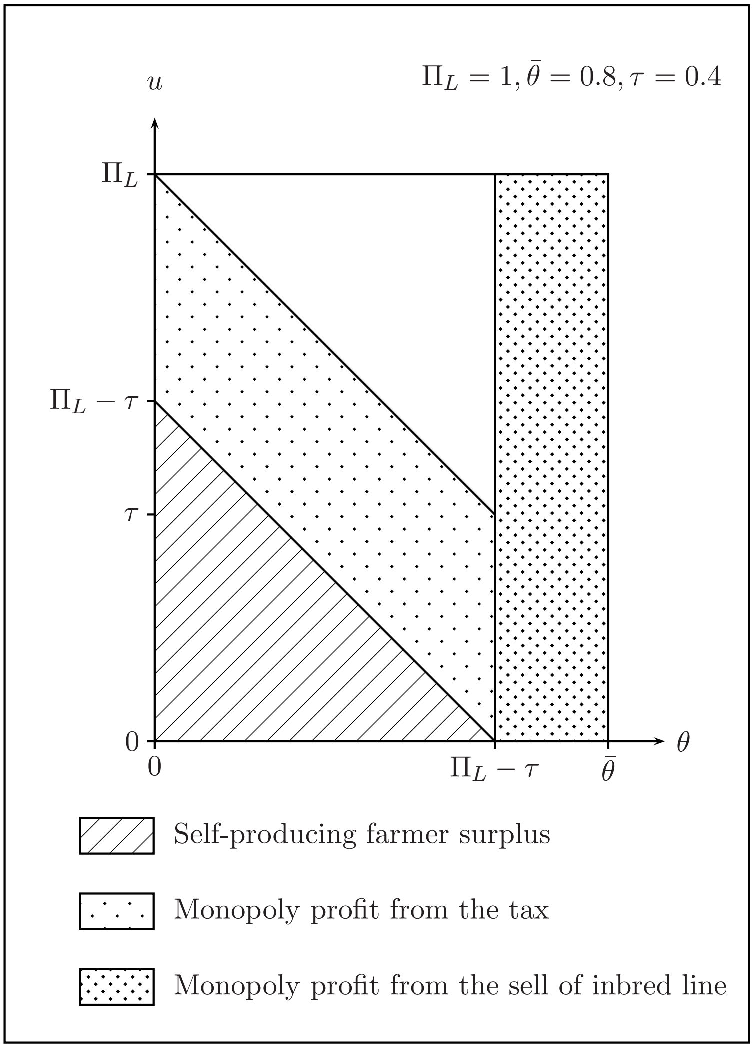

Figure 2: Effect of tax on the monopoly profit and surplus with no commitment

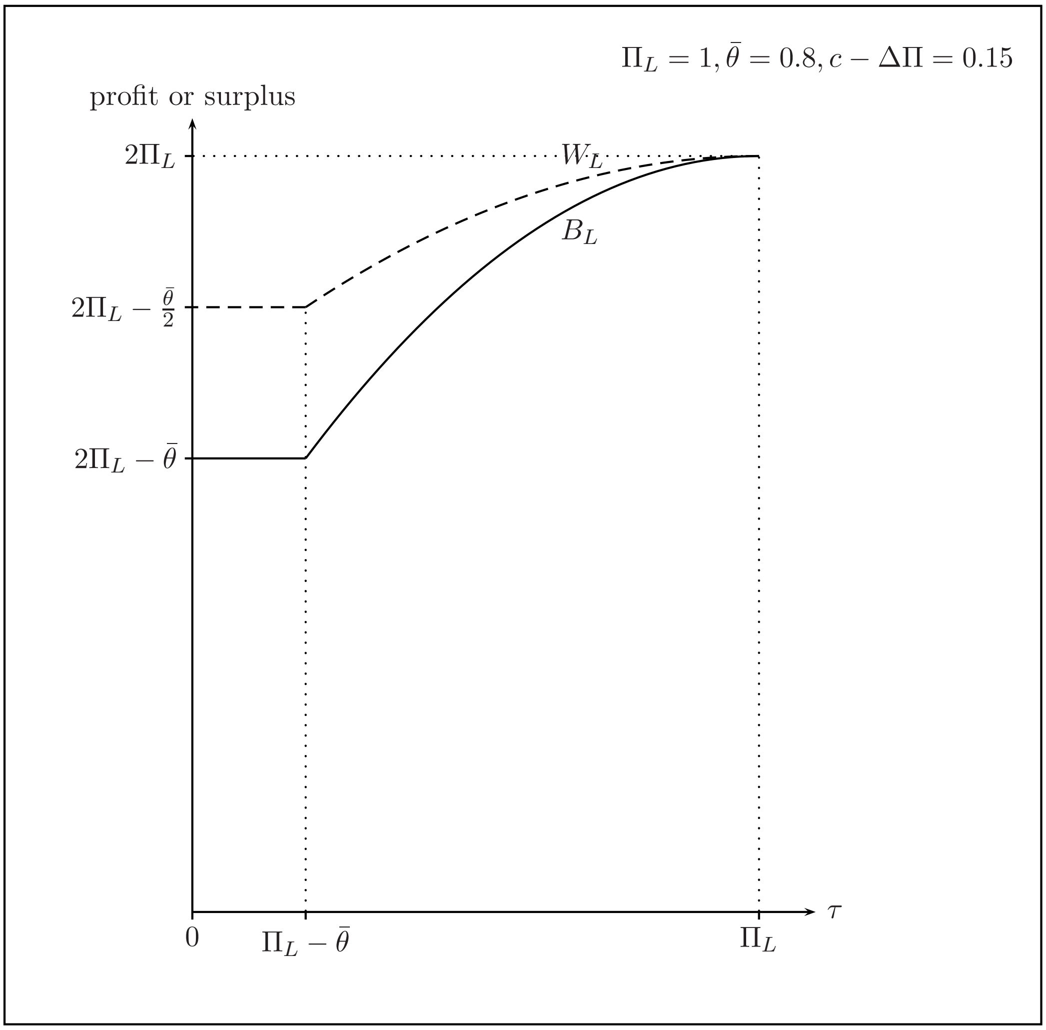

Figure 3: Choice of the type of seed by a mono-seed monopoly with tax (with non commitment when selling inbred only)

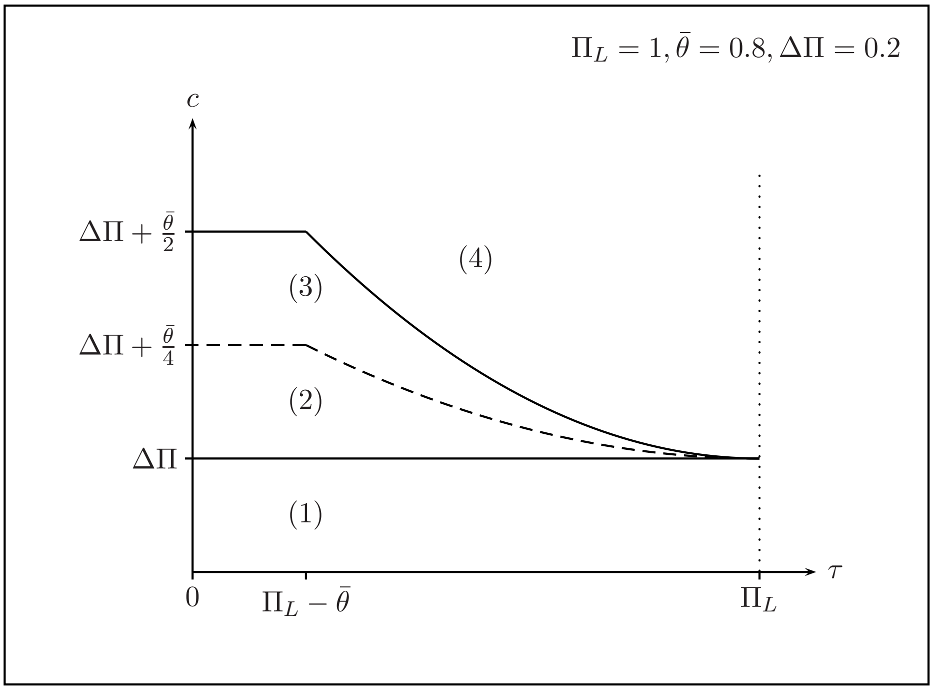

Figure 4: Two periods surplus sharing when the monopoly sells both inbred and hybrid at the period 1 (multiseed monopoly)

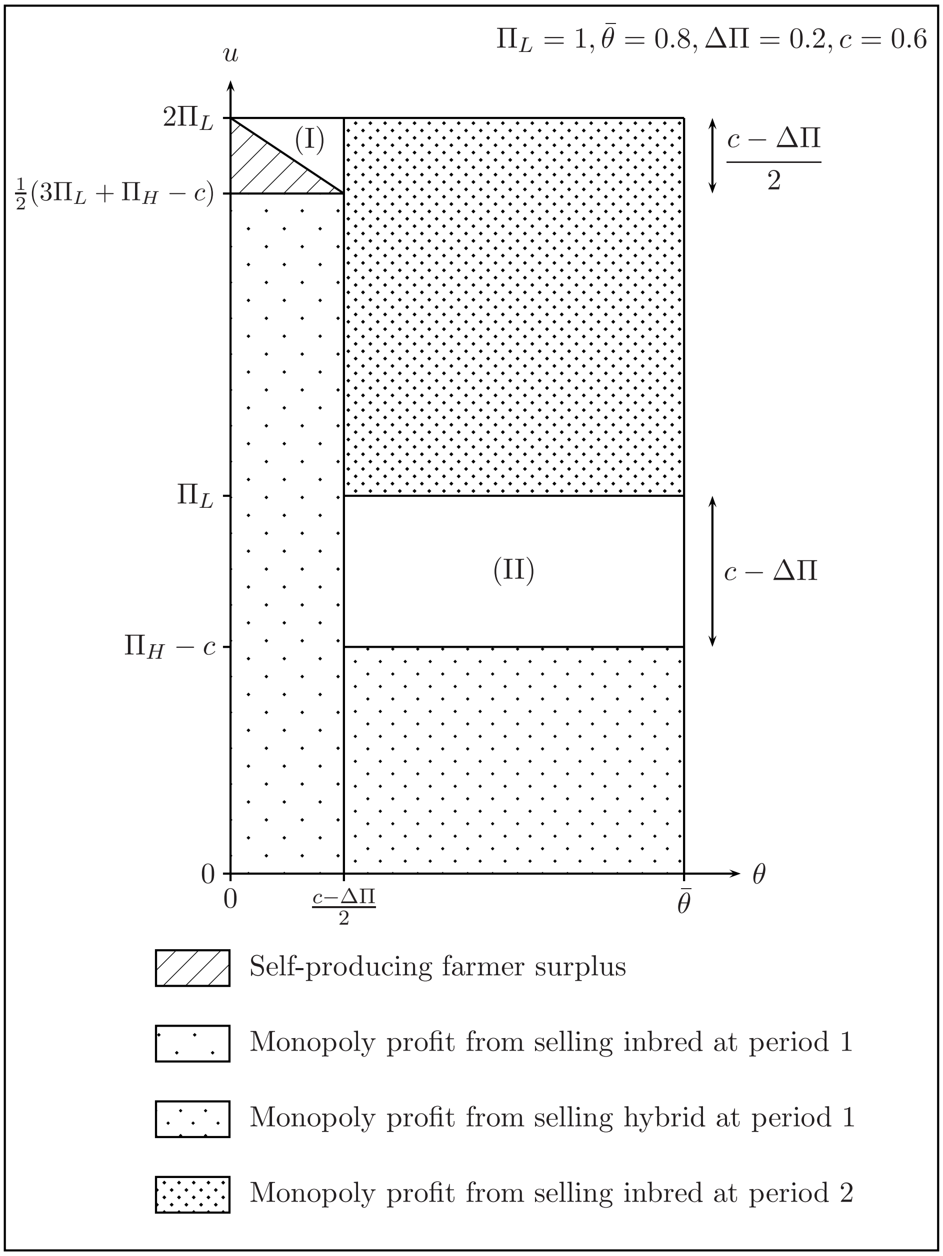

Figure 5: Monopoly profit and surplus with multi-seed monopoly, tax (and no commitment when selling inbred line only) ($c > \Delta\Pi + \frac{4\bar{\theta}}{3}$)

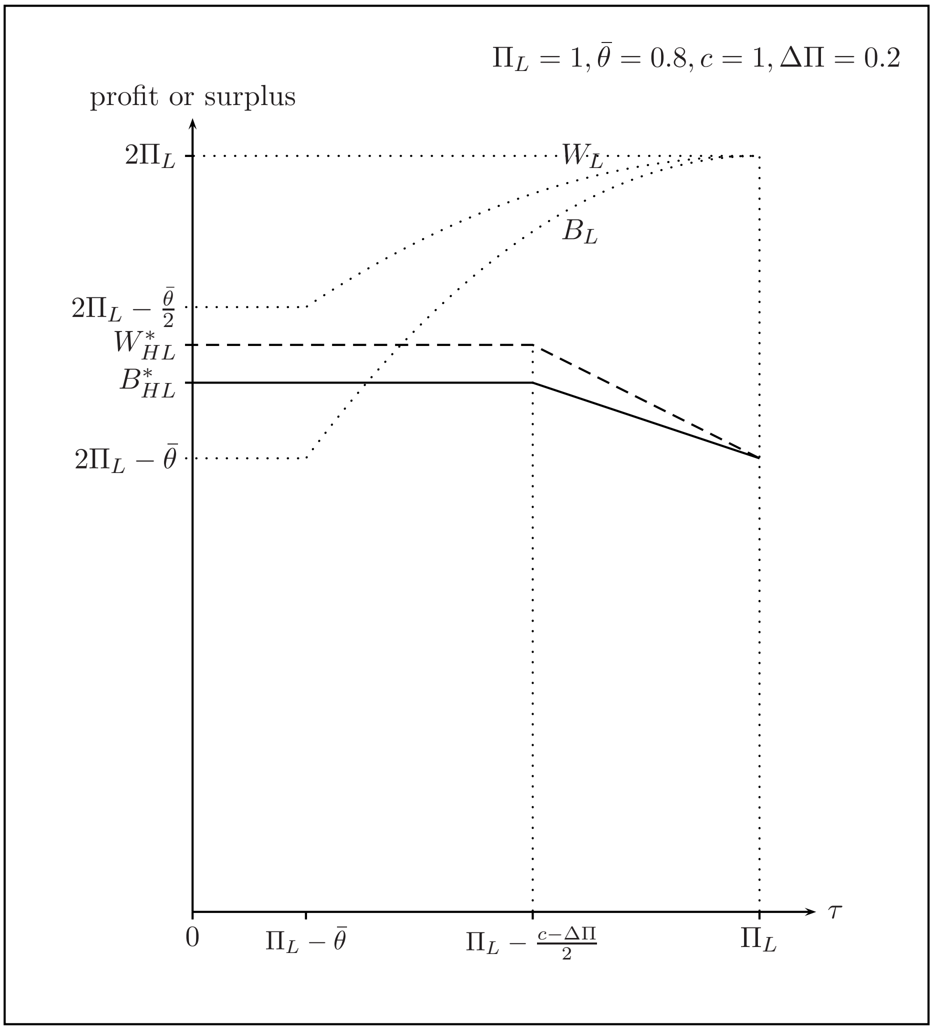

Figure 6: Choice of the type of seed by a multiseed monopoly with tax (with non commitment when selling inbred only)