Research incentives and tradeoff for improving productivity of different crops

Stéphane Lemarié Sébastien Parenty

UMR GAEL, INRA-CNRS-Univ. Grenoble-Alpes, France

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Abstract

This paper addresses the balance between different crops and its determination by research investment. This balance results from the cropping-plan decision of the farmers. This decision depends on various factors such as the seed performance, the pest problems, the output prices, etc. We show how the introduction of a productivity decrease due to the market size of each crop is likely to set out a more equilibriated market. Further, our model analysis the main determinants of research investment by a monopoly, and shows that this investment tends to equilibrate the market.

1 Introduction

Crop diversification is at the core of agricultural economics issues. It is expected that a more productive crop should be more often used in the crop rotation and consequently in cropping-plan. However this increased frequency may have some limits, in particular because it generally leads to more frequent pest problems or, also, to decreasing output prices. There is consequently an interest for having crops with relatively equilibrated productivity level in order to maintain a minimum level of crop diversification (Meynard et al. 2013). In this paper we focus more particularly on crop genetic improvement that is one important determinant of crop productivity. We more particularly analyze the market incentives for investing in research for various crops.

This economic issue is related to the economic literature in the drivers of the innovation. The survey by Cohen (2010) shows that these drivers are related to industry structure, appropriability (e.g. Intellectual Property Rights), demand (e.g. market size) and technological opportunities. In the current paper, we are more particularly interested by market size. From a theoretical point of view, research investment should be considered as a fixed cost, so that firm have more interest to invest in large market to better cover this cost. This hypothesis is generally confirmed by empirical analysis. Recent empirical analysis applied to the pharmaceutical industry shows a positive relationship between product innovation (new drugs) and the market size related to the different type of diseases, or drug classes (Acemoglu et Linn 2000, Dubois et al. 2011). In the case of agriculture, and more particularly seed supply, Charlot et al. (2015) show that the market size for different cash crops have a positive effect on the number of new product (seed varieties) introduced each year. The market size in their analysis is measured by crop acreage and a dummy related to crop with hybrid seed. Hence, as one crop becomes more frequently used by farmers, we can expect seed companies to invest more in research for this crop, leading consequently to more disequilibrated productivity level between these crops. Hence, this lack of R&D in crops with relatively small market size is likely to increase the productivity difference between seeds, leading therefore to create orphan markets, that is to say markets where just a few innovations occurs.

In this paper, we model a situation with a representative farmer allocating its land among two crops. This allocation is determined by the seed productivity and price of each crop. Hence, the allocation of the farmer determines a demand system for seed. We suppose that seed is supplied by a monopoly who decide sequentially some research investment (that determines sed productivity) and seed prices. The two crops are substitutes. However, one important assumption is that, as one crop becomes more frequently used, the farmer faces more important crop protection problems for this crop (leading to yield damages or spending on pesticide to decrease this damage). This is actually a *congestion effect*. As for a golf club (Hart, 1996), the more is the number of members using the green, the less is the value of the club for a new member. The latter would prefer another club if this one was saturated of players. This issue can be solved by increasing the membership price to deter the entrance of new members. Here, the structure of our model is different, in the sense that the congestion effect does not depend on the number of good's users, but rather by the good's market size, taking into account that this market size is normalized to 1, such that the market is just shared between the two crops, that are suffering a complementarity each others. Standard literature on public goods, such as Atkinson and Stiglitz (1987), present the congestion effect as a decrease in a good value when the numbers of users become to high, and generate a negative externality on each consumer. This is also the effect that can shift a good from the denotation "club-good" to "private good", by becoming a rival good, when the good is exludable, or from a public good to a common pool resource, when the good is non excludable.

Our analysis shows different important results. First, we show that the key variable for any player's decision the yield difference between the two crops and the weighing we give to the congestion effect. In order to keep the two products in the market, we show that the difference between the benefit of each crop has to be small, if the congestion effect is high, and conversely, a low congestion effect would lead to create an orphan market to the benefit of the most productive seed. In the latter case, it is not profitable for a farmer to buy the less productive crop anymore. Indeed, by using its market power, the monopoly makes an effort level that is proportional to the market size of the two crops. Hence, even if the monopoly anticipates that disequilibrated use by farmer lead to more important pest problems, the incentives to invest in the crop that is the most frequently used still dominates. A welfare analysis is finally conducted. It shows that, the equilibrium of the game does not correspond to the first best solution. In particular, the disquilibrated investment of the monopoly between the two crops is excessive. The analysis with this basic model is extended by considering a technology (i.e. pesticide use) that can cancel the congestion effect. We show then that a profit maximization research program for a monopoly will lead him to concentrate the effort level on the crop that is more widely used.

The structure of the paper is as follows. The general model is set out in section 2 and the equilibrium of the game is derived in section 3, as well as the main determinants of research investment derived from this equilibrium. Section 4 presents the model in a social welfare maximization approach, while section 5 explores whether the emergence of a new technology, for instance the introduction of a pesticide, is likely to counterbalance the congestion effect for the most productive crop, and how this situation may create an orphan market.

2 The model

The problem examined in this paper can be considered as a two-stage game. In the first stage, a monopoly determines the optimal level of R&D to allocate to two seeds, say A and B, in order to improve their productivity. He then set up the prices that maximize its profit. In the second stage, a representative farmer shares its production by choosing the optimal partition between the two crops, given the fact that each seed is an input to produce each crop. We assume that one crop (A) is more productive initially than the other (B). We solve the game by backward induction, starting with the last stage of the game.

We consider a representative farmer, who is able to produce 2 outputs, corresponding to the two crops A or B. For this purpose he needs to use one input, a seed with price w_i, $i \in \{A; B\}$ for each crop. The revenue generated by one cropis denoted by y_i. [1] Since we assumed that the crop A is more productive then the crop B, we have $y_A \geq y_B$. We also assume that the aggregate market size is normalized to 1, and in a first time that this market is fully covered by the two crops. This assumption will be relaxed at the end of the paper. $\theta \in [0; 1]$ is the share of the market covered by the crop A and $1 - \theta$ is the shared covered by B.

We now turn to the core of our model. We assume here that, for each crop, there is a damage function $k_i \in [0; 1]$, which reduces the crops revenues; We suppose that k_i is increasing with the proportion of the crop i, and for stake of simplicity, we suppose that this increase is linear. More precisely, the farmer will face a damage function equal to $k_A = \alpha(1 - \theta)$ for crop A and $k_B = \alpha(\theta)$ for crop B (with $\alpha \in [0; 1]$). Therefore the farmer looses $\alpha\theta\%$ of its productivity on the crop A and $\alpha(1 - \theta)\%$ of its productivity on the crop B. This is the fundamental assumption we make in our model : the more

[1] Here y_i is an aggregate measure of a revenue generated by the sell of one crop. It takes into account the performance of the seed, as well as the output price of the crop. An important assumption in this model is that the increase of productivity for one crop as no effect on the output prices.

is the weight given to a specific crop, the lower is its productivity. This effect can be observed generally in agricultural economics, especially when a lack of crop rotation leads to a pest adaptation[2], and thereby leads to a productivity decrease. $\alpha = 1$ means that each crop faces a full damage function ($\theta = 1$ leads to no productivity at all, *i.e* the congestion effect is total), while $\alpha = 0$ is the case when we observe no market size effect at all. In a first time, we will consider only the case where this effect is relatively small, *i.e* $\alpha < 0.5$.

The farmer's profit is thus given by :

$$\pi^F = \theta(y_A(1-\alpha\theta) - w_A) + (1-\theta)(y_B(1-\alpha(1-\theta) - w_B)) \tag{1}$$

Hence, the farmer's decision, taking into account that the seeds prices are given, will be to maximize its profit with respect to the market size of each crop, θ. This is the only control variable for him.

Consider now a seed's supplier, who acts as a monopoly on the whole market. Remind that demand for seed A is θ, while demand for product B is $1-\theta$. We also assume that he can produce with a marginal cost of 0 for the two seeds. Thus, profit is here :

$$\pi^M = \theta w_A + (1-\theta)w_B \tag{2}$$

At this stage, the monopoly will have to find the optimal prices $\{w_A; w_B\}$ that maximize its profit. We introduce here a constraint that the farmer have to make a positive profit with each crop.

The figure 1 illustrates the gain of both the farmer and monopoly (as well as total surplus). The upper rectangle areas are the monopoly profit, while the down rectangle areas are the farmer's profit. As we will see, the monopoly pricing will have to maximize the sum of the two areas, taking into account the optimal θ established by the farmer, as well as the feasibility constraints given in the program. One can point out the complementarity between the two crops in this sketch : when θ shifts to the right, meaning that the market is moving to the benefit of the A crop, the B price as well as the farmer's benefit on this crop are changing.

3 Results

3.1 Farmer's allocation of land among crops

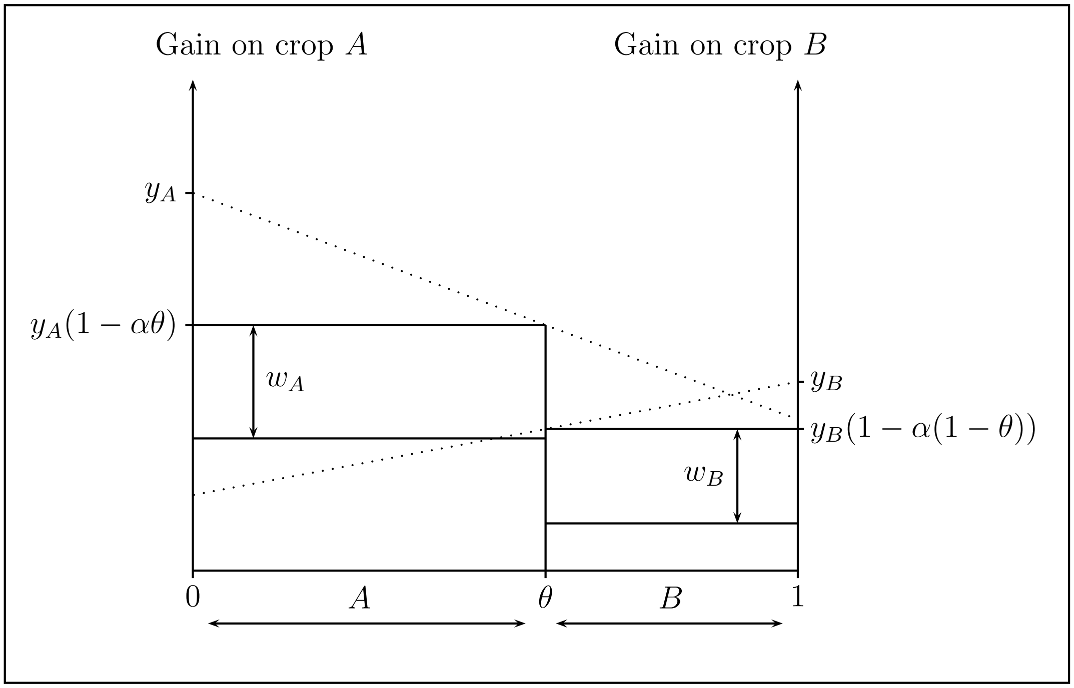
In stage 2, the farmer sets up the optimal crop partition θ^*. From its profit given by (1), and after observing that this expression is concave in θ, which means that the second-order conditions are respected[3], the first order condition gives :

$$\theta^* = \frac{y_A - y_B - w_A + w_B + 2\alpha y_B}{2\alpha(y_A + y_B)}$$

[2]For a more precise and detailed analysis of this issue, see the Meynard (2013).

[3]We have : $\frac{\partial^2 \pi^F}{\partial \theta^2} = -2\alpha y_A - 2\alpha y_B < 0$

Figure 1: Illustration of farmer an monopoly gain for each crop



From this expression, it is clear that the two products are substitutes. Indeed, by computing the cross-price elasticity one can observe, for instance with a variation of the price of seed B, that

$$e_{w_B} = \frac{\partial \theta^*}{\partial w_B} \times \frac{w_B}{\theta^*} = \frac{w_B}{y_A - y_B - w_A + w_B + 2\alpha y_B} > 0$$

, since the latter quantity is positive. Same reasoning can be made on the price of seed A, and we find :

$$e_{w_A} = \frac{\partial (1-\theta^*)}{\partial w_A} \times \frac{w_A}{1-\theta^*} = \frac{w_A}{y_B - y_A - w_B + w_A + 2\alpha y_A} > 0.$$

Thus, augmenting the price of seed A would increase the demand for product B, and *vice-versa*.

It is worthwhile to check whether the margin made on crop A is higher than the one from crop B. This amounts to compare $y_A(1-\alpha\theta^*) - w_A$ with $y_B(1-\alpha(1-\theta^*)) - w_B$. A straight computation leads to :

$$y_A(1-\alpha\theta^*) - w_A \geq y_B(1-\alpha(1-\theta^*)) - w_B \Leftrightarrow y_A - y_B \geq w_A - w_B$$

Thus, if the difference in revenue of the two crops doesn't exceed the difference in the seed's input prices, the farmer will expect a higher profit from the most productive seed. On can see that the latter inequality is also equivalent to $y_A - w_A \geq y_B - w_B$. This means that the latter condition says that the comparison between the two margins made does not depend on the congestion effect. Indeed, Not taking into account this effect would be equivalent, in the profit expression by : $\pi^F = \theta(y_A - w_A) + (1-\theta)(y_B - w_B)$. In this case, the best strategy for the farmer would be to choose $\theta^* = 1$ or 0, by comparing the best margin he could make.

3.2 Pricing decision by the monopoly

We now move to stage 1 and establish the subgame Nash-input pricing decision of the monopoly. Considering the optimal $\theta^* \in [0.1]$ decided by the farmer, the monopoly profit is therefore :

$$\pi^M = w_A \times \frac{y_A - y_B - w_A + w_B + 2\alpha y_B}{2\alpha(y_A + y_B)} + w_B \times \frac{y_B - y_A - w_B + w_A + 2\alpha y_A}{2\alpha(y_A + y_B)}$$

Maximizing this profit with respect to w_A and w_B, and taking into account the farmer's constraints (farmer's profit has to be positive on each crop), the equilibrium seeds prices, market share and profits are given in the following lemma :

Lemma 1. *The equilibrium seeds prices, market share and profits are given in the following table, depending on the difference of the crops revenues :*

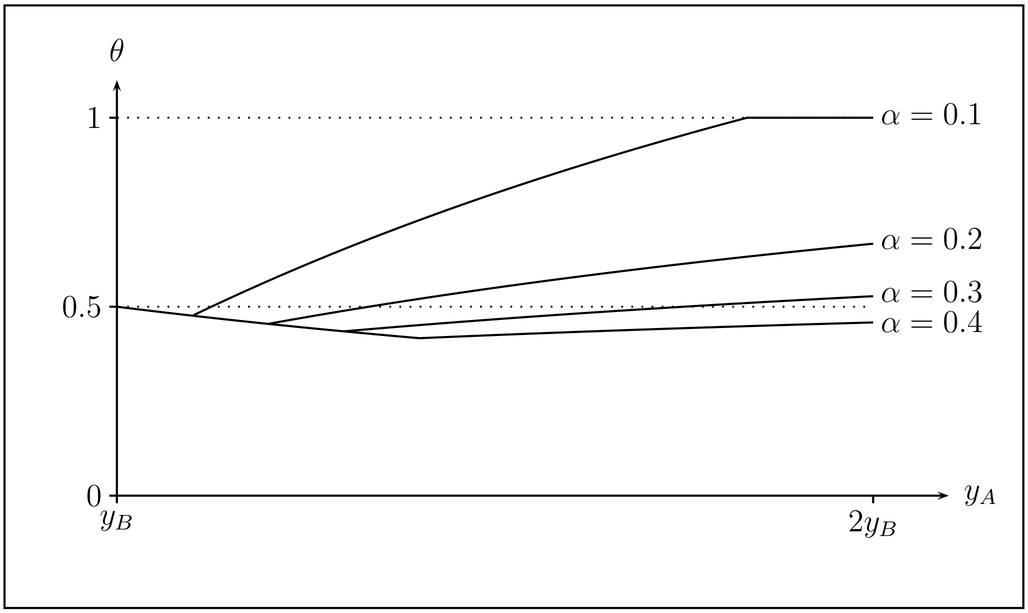
	$y_A \geq (1+\alpha)y_B$	$y_A \leq (1+\alpha)y_B$
w_A^*	$\frac{2y_A^2+(5-2\alpha)y_Ay_B+(1+\alpha)y_B^2}{4(y_A+y_B)}$	$\frac{y_A(y_A+y_B-\alpha y_B)}{y_A+y_B}$
w_B^*	$\frac{(5-4\alpha)y_Ay_B+(3-\alpha)y_B^2}{4(y_A+y_B)}$	$\frac{y_B(y_A+y_B-\alpha y_A)}{y_A+y_B}$
θ^*	$\frac{y_A-y_B+3\alpha y_B}{4\alpha(y_A+y_B)}$	$\frac{y_B}{y_A+y_B}$
π^M	$\frac{y_A^2-2(1+\alpha(4\alpha-7))y_Ay_B+(1+\alpha)^2y_B^2}{8\alpha(y_A+y_B)}$	$\frac{y_Ay_B(2-\alpha)}{y_A+y_B}$
π^F	$\frac{(y_A-(1+\alpha)y_B)(y_A+(3\alpha-1)y_B)}{16\alpha(y_A+y_B)}$	0

Proof : See Appendix 1

In view of the results some remarks can be made. First of all, two cases have to be considered depending on the revenue difference between the two crops. If this difference is high ($y_A \geq (1+\alpha)y_B$), and thus the farmer can make a strictly positive profit on crop A, given that its constraint on B binds. On the contrary revenue difference between the two crops is low ($y_A \leq (1+\alpha)y_B$), and the whole surplus become is captured by the monopoly, leading the farmer to make 0 profit. Actually, if the monopoly would leave a margin on the two crops, he could be better off by another pricing, where at least one constraint binds. So we can affirm that the monopoly will always bind one at least one constraint, with two strategies :

- Binding the other constraint, and then the monopoly is taking the whole surplus, without maximizing the size of the cake. Actually, the price of the second crop is set up so that the two constraints are binding.

Figure 2: θ^* depending on the revenue difference between the two crops



- Searching an optimal θ^* by leaving a flexibility on it, and leaving a small part of the surplus to the farmer, by maximizing the size of the cake.[4],

The second important remark concerns the equilibrium market share θ^* with optimal prices. The figure 2 plots θ^* with different values of α and revenue difference. As y_A increases, the share tends to decrease, up to the border $y_A = (1+\alpha)y_B$, and then increases. This means that if the revenue difference between the two seeds is sufficiently low, the market share doesn't depend on the weighing given to the congestion effect. When the difference between the revenue tends to be sufficiently high, then the market share rises to the benefit of the more productive crop. If the congestion effect is high ($\alpha > 0.4$), the less productive crop catch the majority of the market even with important revenue difference. On the contrary, if the congestion effect is very low ($\alpha < 0.2$), the A crop will dominate the market when the difference between the revenue becomes higher. This can be mathematically resumed as :

As a third remark, it is worth to see that $w_A^* > w_B^*$ in both cases, whatever the value of α is. This result captures the fact that the most productive seed will be always more expensive to purchase, given the fact that the little surplus let by the monopoly comes from this species.

All those results lead us to the following proposition :

Proposition 1. *If the congestion effect is high, a monopoly pricing won't create an orphan market to the benefit of the highest productive seed, but rather will tend to*

[4] We can here verify that the feasibility constraints on θ holds, *i.e* $\theta^* \in [0;1]$. θ^* is always positive, since $y_A - y_B + 3\alpha y_B \geq 0$, and also lower than 1 if and only if we impose a lower bound to α, where $\bar{\alpha} > \frac{y_A - y_B}{4y_A + y_B}$.

create a little disequilibrium in the favor of the less productive crop. Conversely, a low congestion effect would lead to create an orphan market to the benefit of the more productive seed.

3.3 R&D investment by the monopoly

We assume now that the monopoly has the opportunity to increase crops yield, by investing in research and development. Recall that, for $y_A \leq (1+\alpha)y_B$, we have : $\pi_M = \frac{y_A y_B(2-\alpha)}{y_A+y_B}$. In order to see what seed, for an equivalent investment, would be preferred to improve, we just have a look on comparative statics :

$$\frac{\partial \pi^M}{\partial y_A} = \frac{y_B(2-\alpha)(y_A+y_B) - y_A y_B(2-\alpha)}{(y_A+y_B)^2} \leq \frac{\partial \pi^M}{\partial y_B} = \frac{y_A(2-\alpha)(y_A+y_B) - y_A y_B(2-\alpha)}{(y_A+y_B)^2}$$

This inequality leads to $y_A \geq y_B$, which is always true. Thus, the condition is determined by $\alpha \geq \frac{y_A}{y_B} - 1$: when the productivity difference is small, it is more profitable for the monopoly to invest in R&D in the improvement of the less productive seed B. This will have as an effect to reequilibriate the market to the benefit of A, until the limit $y_A = y_B$, where $\theta^* = \frac{1}{2}$, that is to say a perfectly equilibrium in the market share.

Computations in the other case are not straightforward, and depends on the value of α. Nevertheless, we present here the condition. If α is low, then it is more profitable to focus the R&D effort level on A. On the contrary, if $\alpha > 0.3$, it is thus preferable to improve the B productivity. The first case leads directly to cover the market with A, while in the second case, we tend to see the market share to the benefit of crop B, such as in figure 2. Improving A more than B is equivalent to shift in the sketch from the left to the right, and *vice-versa*. We then have :

Proposition 2. *If the difference in revenue between the two seeds is initially low, a profit maximizing R&D program always tend to equilibrate the market until an equal sharing ($\theta^* = 0.5$). On the other side, when a monopoly faces a bigger gap between the seeds productivity, a low congestion effect will lead to create an orphan market, to the benefit of the more productive crop, while an increasing congestion effect would tend to equilibrate the market.*

4 Welfare analysis

In this section, we will consider the social planner point of view[5] :

$$W = \pi^F + \pi^M = \theta(y_A(1-\alpha\theta)) + (1-\theta)(y_B(1-\alpha(1-\theta)))$$

Recall that from figure 1, the surplus transfer between the monopoly and the farmer is the segment with length w_A, for crop A. By canceling the seed's prices in the

[5] Here we define the social surplus by the sum of the two profit. One could see this equivalent to a cooperative structure. Indeed, if the farmers are also the firm's shareholders, and can benefit from its profit, then the cooperative profit is the same than the social surplus.

expression of the social surplus, the objective becomes not to share the "cake", with the most profitable situation for the two players, but rather to make the cake as big as possible. Then, maximizing then this function with respect to θ is straightforward and we found :

$$\theta_S^* = \frac{y_A - y_B + 2\alpha y_B}{2\alpha(y_A + y_B)}$$

which is exactly the value we have obtained with a monopoly, for $w_A = w_B$. The special case $w_A = w_B = 0$ would represent a market with perfect competition, where producers have to charge the price at the marginal cost, that is to say 0. One important thing to point out is, compare to the optimal θ^* found previously in a monopoly market structure, and defining an equilibriated market as close to one half, a social surplus maximizing program will always tend to reach a better equilibrium in the market :

Proposition 3. *If the difference in revenues ($y_1 - y_B$) between the two crops is low, the sharing of the market that maximize the social welfare is more equilibrated compared to the monopoly. On the contrary, when the difference in revenues is high, this sharing will be accentuated by a social planner, to the detriment of the less productive species.*

Proof : Indeed, it is straightforward to check that $\theta^* \leq \theta_S^*$ in both cases. This means that when the market equilibrium is more on the B side, then this optimal social value share is higher (closer to one-half). On the contrary, when a monopoly market structure set up an optimal θ^* to the benefit of crop A, a social planner would also increase the value of the share, to the benefit of crop A.

The optimal social surplus is given by :

$$S^* = \frac{y_A^2 + 2(\alpha(2-\alpha) - 1)y_A y_B + y_B^2}{4\alpha(y_A + y_B)}$$

Without surprise, this quantity is always greater than the surplus we found previously, where farmer's profit maximization leads to find the optimal θ. This correspond actually to the first-best solution. We can also point out that the latter expression is always greater than the one found in a monopoly-representative farmer economy. Since the social planner goal is to maximize the size of the cake, rather than find the best allocation between the players, regardless of their profit, a cooperative structure will better equilibriate the market.

5 Extension

5.1 The introduction of a new technology

We now consider that it is possible for the farmer to rule out the congestion effect, by using a new technology[6] at cost w. We present the case where the most productive seed

[6] By "technology", we consider here for instance the introduction of a new input, a pesticide, that could eliminate the pest damages caused by a lack of crop rotation.

A, can benefit from this technology[7]. For the sake of simplicity, we consider only in this part the case with the highest congestion effect, that is to say $\alpha = 1$. Thus, the profit from B remains the same, while the profit from A don't loose any productivity anymore. The choice to use or not the pesticide (recall that using a pesticide is equivalent to set up $z_A = 1$, is made by comparing the profits with and without the technology. If the latter situation is more profitable, then the farmer won't adopt the technology :

$$z_A^* = \begin{cases} 0 & \text{if } \theta \geq \frac{w}{p_A y_A} \\ 1 & \text{otherwise} \end{cases}$$

Hence, the farmer's profit is :

$$\pi^F = \theta(y_A - w_A - w) + (1-\theta)(y_B\theta - w_B)) \tag{3}$$

And then the optimal θ^* is found as previously :

$$\theta^* = \frac{y_A - w_A - w + y_B + w_B}{2y_B}$$

All the approach we had in the first section remains the same for the monopoly's profit maximization program. We present here directly the results :

Lemma 2. *At stage 2, the Nash-input price equilibrium are given by :* $w_A^* = y_A - w$*;* $w_B^* = \frac{y_A+y_B-w}{2}$*. The crop B still is in the market as long as* $y_A p_A - w \leq y_B p_B$*. If the latter condition is not respected, then crop A will cover the market.* $\pi^M = \frac{(y_A-w)(y_A+6y_B-w)+y_B^2}{8p_B}$ *and* $\pi^A = \frac{(w+y_B-y_A)^2}{16y_B}$ *and* $\tilde{\theta} = \frac{3}{4} + \frac{y_A-w}{4y_B}$

One can see that now the monopoly charges a w_A price such as the farmer makes 0 profit on this crop, and can nevertheless catch a little surplus on crop B. The main results of the lemma 2 is that, the market share in this situation is almost cover only by crop A, as long as the difference between the revenues are less than the price of the technology. Without detailing the computations, the same approach can be made to observe what would be a optimal R&D program for a monopoly. Here the results is straightforward: all the research effort level is caught by the A crop, leading *de facto* to the rise of an orphan market :

Proposition 4. *If one crop, in particular the more productive one, can benefit from a technology that can rule out the congestion effect, then the market partition will tend to be cover only by this crop, as long as the price of this technology doesn't exceed the difference in revenue generated by the sell of the two crops. Crop B becomes an orphan market, since no investments to improve its productivity are made anymore.*

Note that since the farmer's profit depends only on the little share of crop B, improving the productivity of crop A will tend to rule out B of the market, and then make her no profit at all.

[7] The case where both crops can benefit from this technology is straightforward. Indeed recall that in this case :$\pi^F = \theta(y_A - w_A) + (1-\theta)(y_B - w_B)$. Hence, the choice of the farmer would be to arbitrate between the two crop, by choosing the highest $y_i - w_i$. In its response, the monopoly will charge the highest price possible, that is to say $w_A = y_A$ and $w_B = y_B$. Hence, the farmer choose $\theta = 1$ and makes 0 profit.

5.2 What if the market was not covered ?

All along this paper, we have assumed that the market size was normalized to 1, and had to be covered. If we release this assumption, then the farmer's program will change. In particular, its profit becomes :

$$\pi^F = \theta_A(y_A(1-\alpha\theta_A) - w_A) + \theta_B(y_B(1-\alpha\theta_B) - w_B)$$

This latter expression shows us that now, with respect to the feasible constraint $\theta_A + \theta_B \leq 1$, there is no complementarity or negative spillover between the two crops. Thus, when the farmer will choose the optimal partition, he will have to maximize its profit with respect to $\{\theta_A;\theta_B\}$ independently. It gives :

$$\begin{cases} \theta_A^* = \frac{y_A - w_A}{2\alpha y_A} \\ \theta_B^* = \frac{y_B - w_B}{2\alpha y_B} \end{cases}$$

Then, a monopoly[8] will charge the optimal price by maximizing this quantity, say for A: $\pi_A^M = w_A \times \frac{y_A - w_A}{2\alpha y_A}$ and we have directly: $w_A^* = \frac{y_A}{2}$. Thus, we have: $\theta_A^* = \theta_B^* = \frac{1}{4\alpha}$, and $\pi_F = \frac{y_A + y_B}{16\alpha}$.

Hence, if $\alpha > \frac{1}{2}$, the best solution for the farmer is to not cover the market[9]. If $\alpha \leq \frac{1}{2}$, then the farmer can also be better off by charging $\theta^* = \frac{1}{2}$, independently of the values taken by the congestion effect coefficient. Actually, he can always be better off by not covering the market, to the detriment of the monopoly. This situation rises the problem of information in our model: since the monopoly plays the game first, our analysis in the first part is done when she assumes the fact that the market will be covered. Since the farmer's profit is quite different regardless of the way he will face the market, the monopoly has to know what program will be considered by the farmer. A fully rational behavior for the farmer would be to never cover the market, or covering it with a perfect symmetry, and see the input partition as symmetric. Nevertheless, we made the choice to focus our attention in this paper to the case where the market has to be covered by the farmer's decisions.

[8] Here the assumption of a monopoly market structure is equivalent to a situation when a duopoly structure occurs. Indeed, without any complementarity between the two crops, everything happen exactly as if two different firms was providing two different seeds.

[9] Since $\frac{y_A + y_B}{16\alpha} > \frac{(y_A - (1+\alpha)y_B)(y_A + (3\alpha - 1)y_B)}{16\alpha(y_A + y_B)}$ always.

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Appendix

Proof of Lemma 1

- if $y_A \geq (1+\alpha)y_B$ The monopoly's profit function is concave, and its Hessian matrix is semi-definite negative. Unfortunately, there is no point at which the gradient is nil. Recall as well that the farmer's profit has to be positive on both crops. Hence:

$$\begin{cases} y_A(1-\alpha\theta) \geq w_A \\ y_B(1-\alpha(1-\theta)) \geq w_B \end{cases}$$

Thus, to maximize its profit, the monopoly will have to bind one constraint, and redo the maximization with respect to the other contraint, by using the concavity of the function. Starting with the first constraint in the previous system leads to :

$$\begin{aligned} w_A = y_A(1-\alpha\theta) \Rightarrow w_A &= \frac{y_A(3y_B - 2\alpha y_B + y_A - w_B)}{y_A + 2y_B} \\ \Rightarrow w_B^* &= \frac{(1+\alpha)y_A^2 + (5-2\alpha)y_A y_B + 2y_B^2}{4(y_A+y_B)} \\ \Rightarrow \pi^F &= \frac{y_B - (1+\alpha)y_A}{4(y_A+y_B)} \leq 0 \end{aligned}$$

which is impossible. Binding the second constraint leads then to :

$$\begin{aligned} w_B = y_B(1-\alpha(1-\theta)) \Rightarrow w_B &= \frac{y_B(3y_A - 2\alpha y_A + y_B - w_A)}{2y_A + y_B} \\ \Rightarrow w_A^* &= \frac{2y_A^2 + (5-2\alpha)y_A y_B + (1+\alpha)y_B^2}{4(y_A+y_B)} \end{aligned}$$

Now, every constraint of the model are respected. Thus, we find the results : $w_A^* = \frac{2y_A^2+(5-2\alpha)y_Ay_B+(1+\alpha)y_B^2}{4(y_A+y_B)}$; $w_B^* = \frac{(5-4\alpha)y_Ay_B+(3-\alpha)y_B^2}{4(y_A+y_B)}$; $\theta^* = \frac{y_A-y_B+3\alpha y_B}{4\alpha(y_A+y_B)}$; $\pi^M = \frac{y_A^2-2(1+\alpha(4\alpha-7))y_Ay_B+(1+\alpha)^2y_B^2}{8\alpha(y_A+y_B}$ and $\pi^F = \frac{(y_A-(1+\alpha)y_B)(y_A+(3\alpha-1)y_B)}{16\alpha(y_A+y_B)}$

-if $y_A \leq (1+\alpha)y_B$ From previously, we know that the results holds if and only if the farmer's profit is positive, which is expressed by the condition $y_A \geq (1+\alpha)y_B$. Then, choosing the maximum value of $\{w_A; w_B\}$ than the farmers can suffer is equivalent to binding the two constraints[10], leading *de facto* to 0 profit for the farmer. We have :

$$\begin{cases} y_A(1-\alpha\theta) = w_A \\ y_B(1-\alpha(1-\theta)) = w_B \end{cases} \Rightarrow \begin{cases} w_A^* = \frac{y_A(y_A+y_B-\alpha y_B)}{y_A+y_B} \\ w_B^* = \frac{y_B(y_A+y_B-\alpha y_A)}{y_A+y_B} \end{cases}$$

Hence, we find $\theta^* = \frac{y_B}{y_A+y_B}$, $\pi^M = \frac{y_Ay_B(2-\alpha)}{y_A+y_B}$, $\pi^F = 0$

[10] As we will see later, this situation is the same than when a duopoly occurs, each firm selling one seed. Since the separated profits are both concave with respect to the price of the seed, and increasing until the best response equilibrium, the optimal strategy for the two firms is to charge a price equal to the constraints, leading the farmer to make no profit.

Proof of proposition 2

We have $\frac{\partial S}{\partial y_B} = \frac{3(y_A+y_B-w)(y_B-y_A+w)}{16y_B^2}$ and $\frac{\partial S}{\partial y_A} = \frac{3y_A+5y_B-2w}{8y_B}$. The second term is always positive, while the first one is positive if and only if $y_B - y_A + w > 0$. One can note that in this latter case, an increase in crop A's yield will decrease the profit of the farmer, since $\frac{\partial \pi}{\partial y_A} = \frac{y_A-w-y_B}{8y_B} < 0$.

Proof of Lemma 2

Recall the expression of the farmer's profit :

$$\pi = \theta(y_A(1-\theta+\theta z_A) - z_A w - w_A) + (1-\theta)(y_B(\theta+(1-\theta)z_B) - z_B w - w_B)$$

Taking the first derivative with respect to θ give :

$$\frac{\partial \pi}{\partial \theta} = 0 \Leftrightarrow \theta = \frac{y_A - z_A w - w_A + y_B + z_B + w_B - 2y_B z_B}{2(y_A(1-z_A) + y_B(1-z_B))}$$

For $\{z_A; z_B\} \neq \{1; 1\}$. The second-order conditions :

$$\frac{\partial^2 \pi}{\partial \theta^2} = 2y_A(z_A - 1) + 2y_B(z_B - 1) < 0$$

is respected, so it can give us the optimal value of θ. If $\{z_A; z_B\} = \{1; 1\}$, then profit is given by : $\pi = \theta(y_A - w_A) + (1-\theta)(y_B - w_B)$. Maximizing this quantity with respect to θ leads directly to : $\theta = 1$ if $y_A - w_A \geq y_B - w_B$ and 0 otherwise.

Profit maximization is now not straightforward. the objective function is concave in $\{w_A; w_B\}$. Indeed, $\frac{\partial^2 \pi^M}{\partial w_A \partial w_B} = 2$ and the Hessian matrix is therefore :

$$\begin{pmatrix} -2 & 2 \\ 2 & -2 \end{pmatrix}$$

which is semi definited negative. But there is no point at which the gradient is nil. The solution is thereby a corner solution : one of the two constraint binds. To determine the optimal profit, we then have to compare the two profits obtained with the two binding constraints. Recall that the farmer's profit is given by :

$$\pi^A = \theta(y_A - w - w_A) + (1-\theta)(y_B\theta - w_B)$$

- $w_A = y_A - w$:

$$\pi^M = \frac{w_B + y_B}{2y_B} \times (y_A - w) + \frac{y_B - w_B}{2y_B} \times w_B$$

Now we can take the first-order conditions to find w_B^*, and we have : $w_B^* = \frac{y_A+y_B-w}{2}$.

Hence, $\pi^M = \frac{(y_A-w)(y_A+6y_B-w)+y_B^2}{8y_B}$

- $w_B = y_B\theta \Longleftrightarrow w_B = y_A - w - w_A + y_B$. Replace this quantity leads to : $\theta = \frac{2y_A-2w-2w_A+2y_B}{2y_B} > 1$, which is impossible. Thus, we take the previous values and constraint, and we achieve the proof.