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The Economics of Royalty Rates in Plant Breeding*

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Abstract

In the seed sector, for some self-pollinated varieties such as wheat, innovative breeders compete directly with self-producing farmers for commercializing their new seed varieties. The use of farm-saved seed (FSS) can reduce breeders' incentive to innovate. Several countries have established different royalty systems for both certified seed and FSS to reduce such inefficiencies. In this article, we develop a theoretical model to compare these different systems. More precisely, we compare six different systems by analyzing their impact on the incentive to innovate, as well as production efficiencies at both the seed and agricultural production levels. We show that royalty systems leading to a certain proportion of FSS are welfare improving. The systems leading the highest total welfare levels are those in which the royalty level on FSS is regulated, i.e., either defined directly by the regulator (French or UK systems) or imposed at the same level of certified seed (Australian system). When all economic effects are taken into account, the Australian system performs better with high research costs. Conversely, with low research costs, the best system is either the French or the UK system, depending on the relative cost of producing FSS *vs.* certified seed.

Keywords: Farm-Saved Seeds, Intellectual Property Rights, Plant Breeders' Rights, Royalty Rates

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1 Introduction

In all industrialized countries worldwide, innovation in the seed market is made mostly by private companies. The capacity of these firms to appropriate part of the benefit from the seed innovation they create is a major driver of their incentive to innovate. Appropriation in the seed sector depends on two main factors: (i) the capacity of the innovator to avoid competitors making products that are very similar to the innovation made by the innovator and (ii) the capacity of the innovator to avoid farmers saving their own seed for free and using it for their own production. In this article, we focus on the second factor and compare different scenarios that affect the farmers' tradeoff between using farm-saved seed (FSS) and buying certified seed (CS). These scenarios covers cases with either no restriction on the use of FSS, prohibition of FSS, or the imposition of a royalty on FSS and different possibilities for the way in which this royalty is defined. This research question is crucial, as we can observe different royalty systems worldwide, and some countries, such as Canada and Japan, are in the process of changing their system to introduce a royalty on FSS. Thus, the objective of this paper is to analyze the economic effects of these different royalty systems.

Three main drivers explain the proportion of FSS and thus, the differences that can be observed among species or countries with regard to intellectual property rights (IPR), seed technology and seed cost.

In the plant breeding sector, based on the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), all countries members of the World Trade Organization (WTO) must establish an IPR system to protect seed varieties. The most common system is a Plant Breeders' Right (PBR) system, the format of which was established by the 1961 UPOV (Union for the Protection of New Varieties of Plants) convention and revised in 1978 and 1991. As in a patent system, a PBR system grants a monopoly right to the innovator. However, a PBR is specific as it provides both a research exemption and a farmers' exemption (also called farmers' privilege). With the *research exemption*, a breeder can use a proprietary variety as a source of genetic material in his breeding program without the permission of the varietal owner. This exemption favors the cumulative aspect of varietal creation by enabling the integration of the trait of the current varieties in future varieties (see Moschini and Yerokhin, 2008; Lence et al., 2005, 2016, for analysis of the economic effects of this research exemption). The *farmers' exemption* enables farmers to use part of their harvest from a proprietary variety as a source of seed for the next production cycle. The conditions of the farmers' exemption have been evolving over time: the 1978 UPOV convention allowed farmers to use FSS without any counterpart, while the 1991 UPOV convention authorized FSS within "reasonable limits and subject to safeguarding of the legitimate interests of the breeder". In some countries that have adopted the 1991 UPOV convention, farmers using FSS have to pay some royalties to breeders. On the side of the PBR system, plant varieties can also be protected by patents in some countries, such as Australia, Japan and the US.[1] Research and farmer exemptions do not apply to proprietary varieties protected by patents in these three countries. In Europe and most developing countries, plant varieties are excluded from patentability (Tripp et al., 2007).[2]

The second driver of the proportion of FSS is related to the seed technology that may influence the yield difference between CS and FSS.[3] This difference is significant for hybrid and very small for inbred lines. We generally observe that hybrid seeds are developed for open-pollinated crops such as corn, sunflower, and rapeseed; thus, FSS is absent for these crops. Conversely, seeds are inbred lines for self-pollinated crops because developing and producing hybrids is more difficult and costly. This is the case in particular for straw cereals (e.g., wheat, barley) and legumes (e.g., pea, faba bean). The proportion of FSS is thus high, with FSS being used on half of the surface being a common figure (see Table 1 for more details in the case of wheat).

The third driver of the proportion of FSS is related to seed production cost. CS are generally produced by farmers under contract with seed companies or local seed dealers that have licenses for multiplying proprietary varieties. Hence, the production technologies for CS and FSS share several common features. However, specific additional operations are made for CS that are related to transportation, seed sorting, certification and inventory management. These costs are poorly documented in the literature, except for Gray (2021), who provides a brief qualitative

[1]The patentability of plant varieties in the US is possible in two cases. First, a variety of asexually propagated plants have been protected through a plant patent since 1930. In this case, a plant patent only protects from asexual propagation. Tuberous plants such as potatoes are excluded from plant patents. Compared to a utility patent, the requirements for a plant patent are novelty, distinctness, stability and a description that is "as complete as possible". Second, a utility patent can also be used as IPR to protect plant varieties based on two US court decisions: Diamond v. Chakrabarty, 447 U.S. 303 (1980) and J.E.M. Ag Supply v. Pioneer Hi-Bred International, Inc., 534 U.S. 124 (2001) (Smith, 2008; Curtis and Nilsson, 2012).

[2]In Europe, a plant variety can be indirectly patented through patents on gene functions or with the development of new biotechnologies. However, the farmers' exemption also exists for plant-related patents in Europe. See, for example, Article 9c(1) of the German Patent Act, Article L613-5-1 of the French *Code de la Propriété Intellectuelle* or Article 60.-(5)(9) of the UK Patent Act.

[3]Factors other than seed technology may affect the yield difference between CS and FSS. For example, for some crops (e.g., potatoes), it is difficult for farmers to maintain good sanitary conditions for self-produced seeds. In that case, using FSS is generally riskier, and the expected yield could be lower compared to that of CS.

description of these costs. However, we expect that because of the additional costs of CS, FSS should be more attractive for farmers, at least in some situations.

To summarize, the PBR system allows the use of FSS except in rather particular cases (e.g., GM soybean[4]). The main barrier that prevents farmers from using FSS is seed technology and, more particularly, the fact that seeds can be hybrids instead of inbred lines for some crops. For most self-pollinated crops, seeds are inbred lines, thereby enabling the production of FSS. In these cases, the proportion of FSS is determined by the yield difference between FSS and CS, the production cost of the two types of seeds and the royalties paid to the breeders on CS and possibly FSS.

The royalty systems for self-pollinated crops are very different worldwide. This is illustrated in Table 1, which details the case of wheat in nine different industrialized countries. In the US, Canada and Japan, no restrictions and no royalties are imposed on FSS. However, there are currently discussions in Canada and Japan regarding the establishment of royalties on FSS (Gray et al., 2017; Sekine, 2021). Australia has established an end point royalty system (EPR) in which farmers have to pay a flat tax on their harvest sold to elevators. The EPR levels are set by breeders and applied to both CS and FSS. In the European Union (EU), the current PBR system authorizes farmers to make FSS with proprietary varieties for 21 different species; however, they have to "pay an equitable remuneration to the holder". [5] Each member of the EU is responsible for setting this equitable remuneration system. In Germany, each breeder chooses a level of royalty for its varieties, with the royalty on FSS representing 50% of the royalty on certified seeds. In France, for most straw cereal varieties, there is a unique royalty level on CS for each species. This royalty is defined by a private organization (SICASOV) that represents national and international breeders. In addition, there is an EPR on FSS that is identical for all varieties of the same crop, which is negotiated by farmer unions, breeders and a specialized public organization. In the UK, which is a former member of the EU, each breeder sets its royalty for certified seeds and the royalty on FSS has been negotiated to represent 52.5% of the average level of royalties on certified seeds.[6]

[4]Soybean is a self-pollinated species, and seeds are inbred lines. In the US, the patent protection of GM traits prevents farmers from using FSS.

[5]Community plant variety rights have been established by Council Regulation (EC) No 2100/94; more specifically, they have been established on the farmer's exemption, Commission Regulation (EC) No 1768/95. Small farmers (harvesting less than 92 tons of cereals) are exempted from paying FSS to the PBR holder.

[6]In France, Germany, the UK and Australia, a private organization collects and redistributes the revenue from royalties; these organizations are the Sicasov, the Saatgut-TreuhandVerwaltungs (STV), the British Society of Plant Breeders (BSPB) and VarietyCentral, respectively.

Table 1: FSS ratio and royalty systems for wheat varieties protected by a PBR system

Country	FSS ratio	CS Royalty	FSS Royalty	FSS Royalty level
The US	15-85%	Variety royalty	⊘	
Canada	60-88%	Variety royalty	⊘	
Japan	8%	Variety royalty	⊘	
Australia	95%	Variety EPR	Variety EPR	100% of CS
France	40-60%	Single royalty	Single EPR	62% (0.9€/t)
The UK	40-60%	Variety royalty	Single royalty	52.5% (5.169£/q)
Germany	40-60%	Variety royalty	Variety royalty	50%
Netherlands	20-40%	Variety royalty	Variety royalty	65%
Spain	65-85%	Variety royalty	Single royalty	1.4€/q

For the US and Canada, the range of the FSS ratio depends on states/provinces. Variety royalty means a royalty charged per unit of CS or FSS, chosen by the breeder for each of its varieties. A single royalty or EPR means that the level is identical among all varieties of the species (e.g. common wheat). Source: Curtis and Nilsson (2012), Gray et al. (2017), Sekine (2021), Sicasov, STV, BSPB, Geslive, VarietyCentral, Eigen Zaai Zaad and authors survey.

The objective of this article is to analyze the properties of different royalty systems in a context where farmers can use either CS or FSS. This analysis is based on a theoretical model where two competing seed companies create and produce one seed variety each, with the two products being horizontally differentiated. Farmers use a certain proportion of both varieties, and for each variety, they decide the proportion of CS and FSS. Seed companies' and farmers' decisions depend on the royalty systems. We compare six different variety systems that represent the diversity of cases that can be observed worldwide. Three main properties of the royalty systems are analyzed successively. First, we study the impact on production efficiency, which covers both seed production and agricultural production made using seeds. Second, we analyze the impact on the market expansion of the crop with respect to alternative production at the farm level. Finally, we analyze the impact of the royalty system on the incentive to invest in research, which determines the performance of the seed varieties. When considering all the effects related to these three questions, we show that the total welfare is higher with a mix of both FSS and CS and for systems that introduce a royalty on FSS. Our analysis also enables the ranking of the different systems depending on the cost parameters (seed production and research), as well as the degree of product differentiation.

Clancy and Moschini (2017) provide a general literature review of intellectual property rights and innovation in the plant breeding sector. More related to our subject, Kingwell (2001) studies different mechanisms for charging farmers for the use of seed, without differentializing between FSS and CS. Seed royalties are defined by a monopoly, and farmers face a risk related to international prices and/or the level of production at the farm (due to potential meteorological impacts). Royalties can be defined in four different ways: per acre, per unit produced, per value of production or per unit of profit. A royalty based on the farmers' profit performs better with risk-averse farmers, while a flat charge on hectares performs better with risk-averse breeders. Our analysis does not consider risk since Kingwell (2001) has already highlighted the best mechanism for charging farmers in this context. Our contribution with respect to Kingwell (2001) is to differentialize between FSS and CS (for both the royalty and the production cost) and to analyze the impact of a regulation on FSS.

The ability of farmers to use FSS implies that varieties could be considered durable goods. Perrin and Fulginiti (2008) show that if farmers are far-sighted and breeders cannot credibly commit to their price decisions, then the Coase conjecture[7] causes the PBR system to be ineffective in regard to giving the proper incentive to innovate to breeders compared to a patent system where breeders can prevent FSS. Ambec et al. (2008) consider a monopolist breeder that can choose between a durable good or a nondurable good strategy for its inbred line variety; otherwise, the breeder can develop a hybrid variety to avoid FSS. Even if choosing hybrid seed is welfare reducing, the breeder could prefer this rather than facing lower seed prices due to FSS for the inbred line. Introducing a royalty fee on FSS enables the breeder's choice to be made more efficiently. Galushko (2008) and Hervouet and Langinier (2018) introduce endogenous investment decisions in this strand of theoretical literature. Galushko (2008) shows that the optimal choice of IPR system between patents or PBRs relies on the relative production cost between FSS and CS. In Hervouet and Langinier (2018), the introduction of a patent system that competes with a PBR system decreases situations of underinvestment but increases situations of overinvestment. Compared to this strand of the theoretical literature, the model presented in the next sections does not take into consideration intertemporal pricing schemes. Empirically, there is no evidence of the presence of the Coase conjecture and durable good strategies in developed countries[8] and the main problem in developing countries is the lack of respect for IPR (Perrin and Fulginiti,

[7] Coase (1972) shows, in the context of durable goods, that even in a monopoly setting, if the monopolist cannot credibly commit to future prices, then we can end up with competitive prices because buyers can anticipate lower prices in subsequent periods.

[8] The level of royalties for a given variety is very stable for many periods (source: SICASOV for France, STV for Germany, VarietyCentral for Australia).

2008).

Farm-saved seed can also be linked to the economic literature on private copying (see Peitz and Waelbroeck, 2006a, for a literature review). Private copying refers to photocopies of printed material made during the 1980s and, more recently, to digital piracy (copies of software, music, film). This literature focuses its analysis on the tradeoff between underprovision (research investment in our model) and underutilization (the demand of seeds in our model). The problem of underprovision could be addressed by increasing copyright protection (Novos and Waldman, 1984). It negatively impacts the copying cost of the consumer and improves the direct appropriation of the producer. Price discrimination is also possible if consumers are heterogeneous in terms of taste for quality and/or copying cost. In the case of indirect appropriation (Liebowitz, 1985), the IP owner can increase the price of the original depending on the number of copies made by the consumer. However, such indirect appropriation is only possible under strong assumptions. Compared to this literature, in our model, there is only direct appropriation through royalty rates on certified seed and FSS, which depends on the royalty system chosen by the public authority. Moreover, farmers cannot sell the copy (herein, FSS) or give it to other farmers.[9] Finally, network effects (Conner and Rumelt, 1991; Belleflamme, 2003) or sampling effects (Peitz and Waelbroeck, 2006b; Gopal et al., 2006) are not considered in our analysis because farmers have access to a large amount of information on commercial varieties; thus, network effects are rather low.

The rest of the paper is organized as follows. The model is presented in Section 2 and followed by the results in Section 3, along with the presentation of the three effects discussed above. In Section 4, a discussion and an extension of the model are presented to link our results with the context and provide clues for the establishment of a policy in terms of royalties on FSS. Finally, Section 5 concludes the paper.

2 The Model

We model competition among seed varieties for a given crop. Two seed companies ($i = 1, 2$) are competing. Each of them owns an intellectual property right on one variety and defines a royalty rate for using this variety. Each seed variety can be produced through two alternative

[9] However, doing so was a possibility in the past even for a protected variety (e.g., in the US before 1995) and it still can be possible in Australia for some varieties, it also can be done illegally; however, this feature is not taken into account in our model.

channels, namely, specialized seed producers that operate on a rather large scale following some quality specifications to produce certified seed (CS) and farmers who produce farm-saved seed (FSS) for their own needs. Demand is represented by a representative farmer who chooses the quantity of each variety and, for each variety, the quantity of CS he or she buys from specialized seed producers and the quantity of FSS he or she produces himself or herself. s_{ic} and s_{if} are the quantities of CS and FSS, respectively, for seed variety i.

In accordance with the seed context for self-pollinated crops described above, we suppose that specialized seed producers are price takers; thus, the price they define is equal to the marginal cost plus the royalty on certified seed defined by the seed company. We also suppose that specialized seed producers have a constant marginal cost, c.[10] The production of FSS is also costly for the farmer, and we suppose that the marginal cost increases linearly with the quantity of FSS. This assumption captures the fact that FSS is produced by different farmers with various levels of efficiency. In other words, some farmers may be very efficient in producing FSS with a cost lower than c, and some may be less efficient with a cost higher than c. Indeed, part of the FSS is produced more efficiently compared to CS is because CS involves additional costs related in particular to transportation and inventory management. However, not all FSS can be produced under a lower cost compared to CS because some farmers may incur opportunity costs for using FSS or because CS is necessary for variety renewal.[11]

As explained previously, some countries have established regulations where farmers have to pay some royalties on FSS. Hence, we also introduce a seed royalty rate on FSS that may be equal to 0 in some contexts. In summary, the (aggregated) cost incurred by the representative farmer is as follows:

$$C(s_{1c}, s_{1f}, s_{2c}, s_{2f}) = \sum_{i=1}^{2} \left(s_{ic} \cdot (c + r_{ic}) + s_{if} \cdot (f \cdot s_{if} + r_{if})\right) \tag{1}$$

The marginal cost of seed production is c for CS and $f \cdot s_{if}$ for FSS (and variety i). r_{ic} and r_{if} are the per-unit royalty rates for CS and FSS, respectively, for the seed variety i.[12] The

[10]Because of this assumption, these specialized seed producers are not explicitly represented as actors in our model.

[11]Variety renewal is impossible with 100% of FSS. Such variety renewal is not integrated into our model we represent seed use during only in one period. Additionally, even with a given variety, farmers may decide to purchase CS after some time to avoid yield loss.

[12]To our knowledge, only linear tariffs exist between breeders and farmers. However, these tariffs are not always based on the quantity of seeds. Indeed, royalties can also be based on the harvest of farmers or their profits. This change can only affect our results if we take into account risk aversion. The effects of risk aversion on the price of seeds have already been studied by Kingwell (2001).

gross benefit from using a given variety is supposed to be different depending on the farmer, as one variety may be more productive than the other in some context and the converse in other context. To represent this diversity, the gross benefit of the representative farmer is modeled with a quadratic and strictly concave utility that follows Singh and Vives (1984):

$$U(s_1, s_2) = y_1 \cdot s_1 + y_2 \cdot s_2 - (s_1^2 + s_2^2 + 2\gamma \cdot s_1 \cdot s_2)/2 \tag{2}$$

where y_i represents a theoretical performance for the land perfectly fitted for the variety i, and s_i is the total quantity of variety i ($s_i = s_{ic} + s_{if}$). The performance corresponds to the per acre gross margin excluding seed expenses. This performance can increase with characteristics that are specific to varieties such as yield or disease resistance, which may lead to pesticide cost savings. The performance also depends on some general factors that are related to the context, such as the price of commodities or the per unit cost of nitrogen. We suppose that, for a given variety, CS and FSS do not differ with respect to their performance. This assumption is made to avoid the overparameterization of the model, and we can actually observe that the performance difference between the two types of seeds can be captured with the seed production costs that are different for the two types of seed. In other words, the seed production cost parameters (c and f) include the cost of producing the seed plus the cost related to performance difference between the two types of seed. In Equation 2, the parameter $\gamma \in]0, 1[$ is the cross elasticity, which captures the substitution among the two seed varieties. The two seed varieties are closer substitutes as γ increases.

The surplus of the representative farmer is defined by the following:

$$FS(s_{1c}, s_{1f}, s_{2c}, s_{2f}) = U(s_{1c} + s_{1f}, s_{2c} + s_{2f}) - C(s_{1c}, s_{1f}, s_{2c}, s_{2f}) \tag{3}$$

The farmer demand results from the maximization of $FS(s_{1c}, s_{1f}, s_{2c}, s_{2f})$. Two configurations will be considered in our analysis with either a covered or a noncovered market. A covered market corresponds to a situation where the total demand is constant and independent of the price. This situation corresponds to a case where the total surface of one crop is not affected by the performance and the pricing of the seed varieties for this crop. This situation may be related, for example, to crop rotations or production contracts. Conversely, with a noncovered market, the surface of one crop expands with an increase in the seed performance or a decrease in the price of the seed varieties for this crop. The demand functions for each of these two configurations will be detailed below.

To analyze the impact of royalties on the incentives to innovate, we suppose that breeders can invest in R&D to increase y_i. More precisely, we suppose that R&D leads to an innovation level k_i, so that $y_i = y_0 + k_i$, y_0 being a common pre-innovation level for both firms. The R&D cost related to the innovation level is equal to $\frac{\alpha k_i^2}{2}$.

The equilibrium and the properties of the model are analyzed under different rules that define the royalty levels (r_{ic} and r_{if}). These rules correspond to different contexts that cover most of the various royalty systems observed worldwide. First, we have two polar systems with maximal or minimal proportions of FSS. In the *base case* (B), there is no royalty on FSS ($r_{if} = 0$), leading to the maximum quantity of FSS. This system corresponds to the situation in North America, for varieties that are only protected by a PBR system, and in most developing countries. Conversely, we also consider the *prohibition case* (P), where FSS are forbidden such that $s_{if} = 0$ (or equivalently, the royalty on FSS is set at $r_{if} = +\infty$). This system corresponds to the GMO and/or a patent system such that the farmer's privilege is removed.[13] This prohibition case cannot represent a situation with the hybrid seed case because the hybrid seed would require different cost parameters. The hybrid seed case will be discussed in Section 4.

We also consider four other royalty systems with positive royalties on FSS. In the *competition case* (C), the royalties are defined by the seed companies. In the *Australian case* (A), the seed companies are constrained to define the same royalty rate on both CS and FSS ($r_{if} = r_{ic} \equiv r_{i.}$).[14] In the *UK case* (U), the royalty on FSS is defined by the regulator prior to the decisions of the seed company. This royalty level is identical for the two seed varieties ($r_{1f} = r_{2f} \equiv r_{.f}$) and defined by the regulator to maximize total welfare. Finally, the *French case* (F) is identical to the UK case except that there is a uniform level of the royalty on CS ($r_{1c} = r_{2c} \equiv r_{.c}$), and this level is defined to maximize the joint profit of breeders. This case is a stylized representation of the French situation in which the royalty level on certified seed is identical for all varieties and collected by the SICASOV, which is a joint organization between seed breeders.

Table 2 synthesizes the timing of the game and the constraints on royalties with the different

[13] See, for example, Bowman v. Monsanto Co., 569 U.S. 278 (2013). This system can also be represented by contracts between farmers and breeders (e.g., technology use agreements) or by genetic engineering, such as terminator technology. To keep this example simple, we do not introduce the fact that breeders have to check if farmers respect the prohibition as Yiannaka (2014).

[14] In the German system, the royalty rate on FSS is only half of the royalty rate on CS. More generally, we can set $r_{if} = v \cdot r_{ic}$, where v is included between $[0, 1]$. For $v = 0$, it returns to the *base case*, while for $v = 1$, it leads to the *Australian case*.

systems. The royalty system is defined at the first stage by the regulator. In systems U and F, this implies that the regulator also defines the royalty level on FSS. The R&D stage corresponds to Stage 2, and at Stage 3, the seed companies define the royalty rates on CS and possibly FSS (for cases A and C). All our analysis herein is limited to the duopoly equilibrium.[15] We remind the reader that the model is analyzed under both the assumption of covered and noncovered markets.

Table 2: Timing for each pricing system

Timing	Agents	Decision	Royalty systems					
			(B)	(P)	(C)	(A)	(U)	(F)
Stage 1:	Regulator	r_{ic}	.	.	.	.	.	.
		r_{if}	.	.	.	.	$r_{.f}$	$r_{.f}$
Stage 2:	Breeders	k_i	k_i	k_i	k_i	k_i	k_i	k_i
Stage 3:	Breeders	r_{ic}	r_{ic}	r_{ic}	r_{ic}	$r_{i.}$	r_{ic}	.
		r_{if}	0	$+\infty$	r_{if}	$r_{i.}$	.	.
or	Cartel	r_{ic}	.	.	.	.	.	$r_{.c}$

3 Results

To disentangle the different properties of the model, our analysis is made under different modeling assumptions. We start by ignoring the R&D stage so that the performance of varieties is exogenous. We first consider the case with a covered market (Section 3.1) to specifically analyze the impact of the royalty system on the production efficiency, which covers both the seed production efficiency of both CS and FSS and the agricultural production efficiency related to the performance seed varieties. Second, we consider the case with a noncovered market (Section 3.2) to analyze the impact of the royalty system on the total quantities of seeds that are sold. Finally, we consider the full version of the model, including the R&D stage (Section 3.3). With this full version, we can then study the impact of the royalty systems on the incentives to innovate and aggregate this effect with those mentioned above to have a full comparison of the royalty systems.

[15] It should be observed that in some cases where y_1 and y_2 are sufficiently different, equilibrium with either predatory or monopoly pricing is also possible.

3.1 Production efficiency (covered market)

We first define the demand system. We suppose here that the total quantity of seeds is constant and, without loss of generality, equal to 1. The demand system is defined by maximizing the farmer surplus (Equation 3) with respect to s_{1c}, s_{1f} and s_{2c} and setting $s_{2f} = 1 - s_{1c} - s_{2c} - s_{1f}$. This maximization is made with given royalty levels. We obtain the following:

$$\begin{cases} s_{1c}(r_{1c}, r_{2c}, r_{1f}) & = \frac{1}{2} + \frac{\Delta}{2(1-\gamma)} - \frac{r_{1c}-r_{2c}}{2(1-\gamma)} - s_{1f}, \\ s_{1f}(r_{1c}, r_{1f}) & = \frac{c}{2f} - \frac{r_{1f}-r_{1c}}{2f}, \\ s_{2c}(r_{1c}, r_{2c}, r_{2f}) & = \frac{1}{2} - \frac{\Delta}{2(1-\gamma)} - \frac{r_{2c}-r_{2f}}{2(1-\gamma)} - s_{2f}, \\ s_{2f}(r_{2c}, r_{2f}) & = \frac{c}{2f} - \frac{r_{2f}-r_{2c}}{2f}. \end{cases} \tag{4}$$

with $\Delta = y_1 - y_2$. We can observe that the FSS quantities of each variety only depend on the royalty levels for this variety, while the total demand (FSS plus CS) for each variety depends on Δ and the royalties on CS of the two varieties. This result can be explained as follows. The first units of seed that the farmer chooses for each variety are FSS because these units are less costly compared to CS. The per unit cost of each additional unit of FSS increases until the point where it is worth choosing CS for the farmer. As a consequence, the quantity of FSS of each variety only depends on the cost parameters for this variety, including the royalty rates for FSS and CS. Once the quantity of FSS is defined for each variety, the rest corresponds to CS, and these quantities depends on the relative performance (Δ) and royalty level of the two varieties ($r_{1c} - r_{2c}$).

The first best quantities correspond to the situation where all royalties are equal to 0. Using the demand system defined in (4), we conclude that the first best quantities are as follows:

$$s_{1c}^{FB} = \frac{1}{2} - \frac{c}{2f} + \frac{\Delta}{2(1-\gamma)} \quad ; \quad s_{2c}^{FB} = \frac{1}{2} - \frac{c}{2f} - \frac{\Delta}{2(1-\gamma)} \quad \text{and} \quad s_{1f}^{FB} = s_{2f}^{FB} = \frac{c}{2f}$$

The equilibrium quantities with all the royalty systems are summarized in Table 3, and the compilation is detailed in Appendix A.1. These results correspond to a duopoly equilibrium that requires Δ to be lower than a certain ceiling $\bar{\Delta}$ which is different depending on the royalty system.

As we consider a covered market, the total quantity is identical with all royalty systems. However, the systems perform differently in terms of production efficiency; this includes seed

Table 3: Equilibrium quantities for Variety 1*

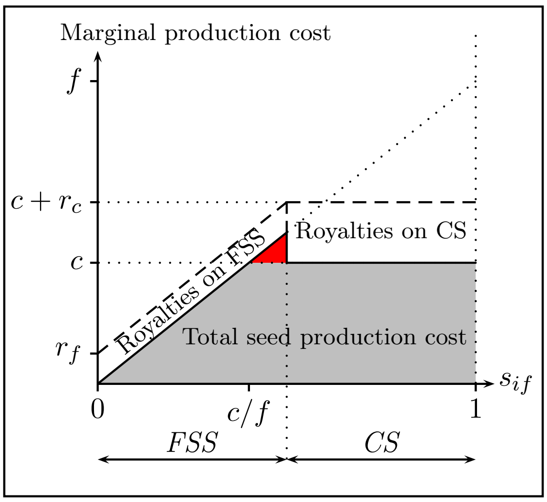
	CS (s_{1c})	FSS (s_{1f})
First Best	$\frac{1}{2} - \frac{c}{2f} + \frac{\Delta}{2(1-\gamma)}$	$\frac{c}{2f}$
Base	$\frac{1}{2} - \frac{c}{2f} - \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} + \frac{(1-\gamma+f)\Delta}{(2(1-\gamma)+3f)(1-\gamma)}$	$\frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} + \frac{c}{2f} + \frac{\Delta}{(2(1-\gamma)+3f)}$
Prohibition	$\frac{1}{2} + \frac{\Delta}{6(1-\gamma)}$	0
Competition	$\frac{1}{2} - \frac{c}{4f} + \frac{\Delta}{6(1-\gamma)}$	$\frac{c}{4f}$
Australian	$\frac{1}{2} - \frac{c}{2f} + \frac{\Delta}{6(1-\gamma)}$	$\frac{c}{2f}$
UK	$\frac{1}{2} - \frac{c}{2f} + \frac{(1-\gamma+f)\Delta}{2(2(1-\gamma)+3f)(1-\gamma)}$	$\frac{c}{2f} + \frac{\Delta}{2(2(1-\gamma)+3f)}$
French	$\frac{1}{2} - \frac{c+f}{4f} + \frac{\Delta}{2(1-\gamma)}$	$\frac{c+f}{4f}$

*Equilibrium quantities for Variety 2 are identical except that Δ is replaced by $-\Delta$.

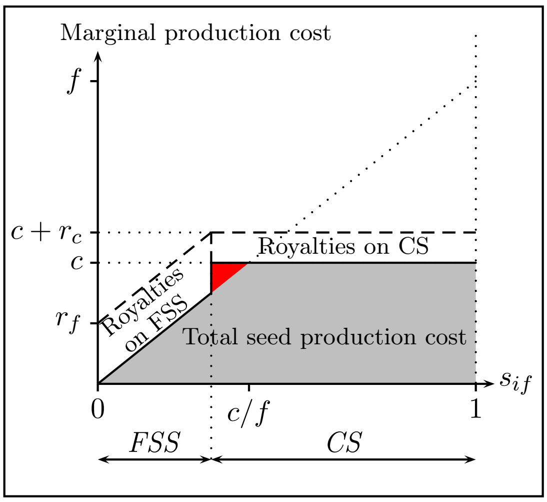
production on the one hand and agricultural production on the other hand. Seed production efficiency depends on total cost (Equation 1), which is determined by the proportion of CS *vs.* FSS for each variety. These proportions differ depending on the seed cost for the farmer, i.e., seed production cost plus royalties. Figure 1 illustrates this: compared to the first best proportion (gray area), the total cost increases (red area) if they are either too much FSS (i.e., $r_c > r_f$, see Figure 1a) or not enough FSS (i.e., $r_c < r_f$, see Figure 1b). Agricultural production efficiency depends on gross profit (Equation 3), which is determined by the proportion of each variety. If $\Delta > 0$, then the proportion of the most productive variety is higher compared to the less productive variety. However, varieties are not perfect substitutes; thus, there is interest in the representative farmer using some of the less productive variety on part of his or her land.

Figure 1: Farmer trade-off between CS and FSS and seed production efficiency

(a) $r_c > r_f$



(b) $r_c < r_f$



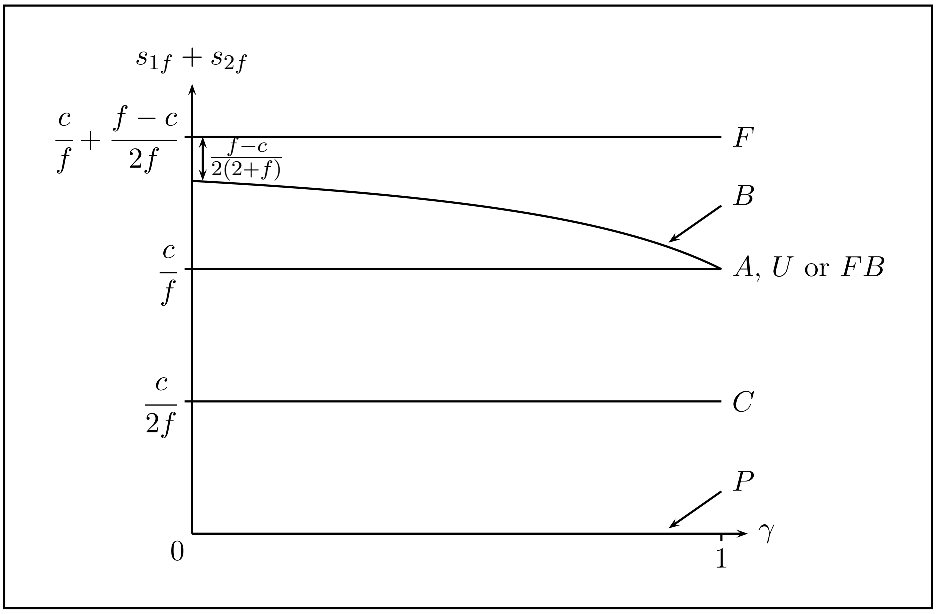
We now analyze the properties of the royalty systems with respect to each of these two components of production efficiency before aggregating these two components.

Royalty systems only differ with respect to seed production efficiency if $\Delta = 0$. In this case, we always have $s_{ic} + s_{if} = 1/2$. Properties of the systems with respect to seed production efficiency are summarized in Lemma 1 and illustrated in Figure 2.

Lemma 1. *With no research and a covered market, having some FSS is valuable, the first best proportion being c/f. If both varieties are performing equivalently ($\Delta = 0$), then*

- *the UK and Australian cases lead to the optimal proportion of FSS;*
- *there is not enough FSS within the prohibition or competition cases; and*
- *there is too much FSS within the base or French cases.*

Figure 2: Quantity of farm-saved seed with no research and the same performance for both varieties ($\Delta = 0$)



As we consider a case with a covered market, all systems leading to identical royalty levels for CS and FSS correspond to the first best proportion of FSS. This result is directly visible from the demand system in (4). This property is observed with the Australian system because, by construction, this system imposes $r_{ic} = r_{if}$. In the UK system, the equilibrium royalty for CS depends on the FSS royalty defined by the regulator. Interestingly, the regulator can define an FSS royalty such that both CS and FSS royalties coincide.

Consider the cases leading to insufficient farm-saved seed. The first straightforward case is case P, where FSS is prohibited. The second case is the case where the seed companies defined competitively the royalty on both CS and FSS. As long as the quantity of FSS is not too important, then its marginal production is low. For this reason, the seed companies define a higher royalty rate on FSS compared to the royalty on CS. This indeed enables the seed company to capture part of the gain related to the lower production cost of FSS. Finally, because of this higher royalty rate, the quantity of FSS is insufficient compared to the first best proportion.

Consider now the cases leading to excessive FSS. The first straightforward case is case B, with no royalty on FSS. In this case, the only way for the seed company to make some profit is to define a positive royalty rate on CS. Because of this higher rate on certified seed, the quantity of FSS is excessive compared to the first best proportion. The second case is case F, where the royalty rate on FSS is defined by the regulator and the rate on CS is defined by the seed company. The only difference with respect to the UK system is that seed companies define a royalty rate that maximizes their joint profit, while this rate is defined competitively in the UK case. Thus, the French system leads to higher royalty rates on CS and, consequently, too much FSS compared to the UK system, which corresponds to the first best proportion.[16]

We now analyze agricultural production efficiency by studying the proportion of each variety. under the assumption that they perform differently. Without loss of generality, we suppose that $\Delta > 0$. This comparison is made under the assumption that all royalty systems lead to a duopoly equilibrium. This requires $\Delta < \bar{\Delta}^F$ because the French system leads to the most restrictive assumption (see Appendix A.1 for details).

Lemma 2. *With no research, a covered market and seed varieties performing differently* ($0 < \Delta < \bar{\Delta}^F$)*,*

- *the French case leads to the first best outcome in terms of varieties proportion* (s_1 *and* s_2)*;*
- *all the other systems lead to an insufficient proportion of the most productive variety; and*
- *the UK and base cases perform better than the three other cases* (P, C *and* A)*.*

This result can directly be established by compiling the total quantity of seeds for variety 1,

[16] Detailed compilation shows that in case F, the difference between the equilibrium rates on CS and FSS is positive and constant. For this reason, the level of the royalty rate on FSS defined by the regulator does not affect the quantity of FSS; thus, there is no way to reach the first best proportion by changing $r_{.f}$.

which is the more productive variety:

$$\underbrace{\frac{1}{2}+\frac{1}{3}\cdot\frac{\Delta}{2(1-\gamma)}}_{=s_1^A=s_1^C=s_1^P}<\underbrace{\frac{1}{2}+\frac{f+2(1-\gamma)}{3f+2(1-\gamma)}\cdot\frac{\Delta}{2(1-\gamma)}}_{=s_1^B=s_1^U}<\underbrace{\frac{1}{2}+\frac{\Delta}{2(1-\gamma)}}_{=s_1^F=s_1^{FB}}$$

As we consider a case with a covered market, all systems leading to the same royalty level for the two varieties lead to a proportion of variety (CS and FSS) that is identical to the first best proportion. More precisely, the first best situation is reached if $r_{1c} = r_{2c}$ and $r_{1f} = r_{2f}$, r_{ic} and r_{if} being possibly different. This property is fulfilled in the French system because the same royalty is defined by the regulator on FSS, and firms cooperate in defining the royalties on SC under the assumption that this royalty is identical for the two varieties.[17]

With all the other royalty systems, the seed companies define the royalty on CS competitively. With the demand for the more productive variety being higher (compared to the other variety), the firm that sells this more productive variety exercises its market power, leading to a higher royalty level for this variety at equilibrium. As a consequence, the quantity for the more productive variety is lower compared to the first best situation. Interestingly, this distortion is less important when the system forces to have the same level of royalty for FSS, and this occurs in the base case or the UK systems. In other words, by having $r_{1f} = r_{2f}$, the equilibrium values of r_{1c} and r_{2c} are closer. This constraint on the royalty level for FSS does not exist under the prohibition, competition or Australian systems, which leads to larger differences between r_{1c} and r_{2c}.

We can now synthesize the ranking of the royalty systems with respect to both the seed and agricultural production efficiency.

Proposition 1. *With no research and a covered market, the highest welfare levels are reached for royalty systems which leads to positive and regulated royalty rates on FSS, and positive quantities of FSS.*

- *If the two varieties perform equivalently ($\Delta = 0$), then the UK and the Australian systems reach the first best situation.*
- *If the two varieties perform differently ($\Delta > 0$), then no royalty system reaches the first best situation. The UK system is the second best, and the third best is either the Australian or the*

[17]Note that if this assumption is removed, the two competitors obtain a higher joint profit by defining a higher price on the most productive variety.

French system.

Proposition 1 synthesizes the results of Lemma 1 and 2. The detailed proof is provided in Appendix A.2. Note that we analyze here the total welfare level instead of seed quantity, as we did with Lemma 1 and 2.

If $\Delta = 0$, we only have an effect related to the seed production efficiency, and the result corresponds to Lemma 1. If $\Delta > 0$, we aggregate the effects related to both seed and agricultural production efficiency. We can observe with Lemma 1 and 2 that some royalty systems enable to reach the proportions of seed that correspond to the first best proportion. However, these systems are different depending on the type of production efficiency that is considered. We can thus understand that the first best welfare level cannot be reached when both effects are aggregated. The UK system corresponds to the second best level because it leads to the first best level in terms of seed production efficiency and to the second best level in terms of agricultural production efficiency. The Australian system performs very well in terms of seed production efficiency but performs poorly in terms of agricultural production efficiency. The converse properties are observed for the French system. When aggregating both, we can show the following:

$$W^A > W^F \quad \Leftrightarrow \quad \Delta < \underbrace{\frac{f-c}{2f} \cdot (1-\gamma)}_{=\bar{\Delta}^F} \cdot \underbrace{\sqrt{\frac{9f}{2(1-\gamma)}}}_{<1 \text{ if } f<2(1-\gamma)/9}$$

Hence, we have $W^F > W^A$ if $f \in [c, 2(1-\gamma)/9]$ and if Δ is high enough. The French system corresponds to the third best level if γ and f are small and Δ is high. Indeed, if γ is small and Δ is high, the royalty difference of CS ($r_{1c} - r_{2c}$) is more important; this increases the interest in French systems. In addition, the disadvantage of the French system is that it leads to excessive FSS. However, this disadvantage is reduced if f is low.

3.2 Total quantity of seed supplied (noncovered market)

We now consider the case with a noncovered market. For sake of simplicity, we restrict the attention to the symmetric case by setting $y_1 = y_2$. The demand system is now as follows:[18]

$$\begin{cases} s_{1c}(r_{1c}, r_{2c}, r_{1f}) & = & \frac{y_0 - c}{1+\gamma} - \frac{r_{1c} - \gamma \cdot r_{2c}}{1-\gamma^2} - s_{1f}, \\ s_{1f}(r_{1c}, r_{1f}) & = & \frac{c}{2f} - \frac{r_{1f} - r_{1c}}{2f}, \\ s_{2c}(r_{1c}, r_{2c}, r_{2f}) & = & \frac{y_0 - c}{1+\gamma} - \frac{r_{2c} - \gamma \cdot r_{2f}}{1-\gamma^2} - s_{2f}, \\ s_{2f}(r_{2c}, r_{2f}) & = & \frac{c}{2f} - \frac{r_{2f} - r_{2c}}{2f}. \end{cases} \tag{5}$$

This demand system shares some features with the demand system obtained with a covered market (Equation 4). More precisely, the FSS quantities of each variety only depend on the royalty levels for this variety, while the total demand for each variety (FSS plus CS) only depends on the royalties on CS of the two varieties. For a given variety, the variable and parameters that are specific to FSS (f and r_{if}) only determine the sharing between FSS and CS but do not influence the total quantity (i.e., $s_{ic} + s_{if}$). As explained above, for each variety, the first unit of seed chosen by the farmer is FSS up to the point where it is less costly to use CS. Hence, the last unit chosen by the farmer is CS. This explains why the total quantity of seeds depends on seed performance (y_0), the average cost of CS ($(2c + r_{1c} + r_{2c})/2$) and the substitution parameter (γ):

$$s_{1c} + s_{1f} + s_{2c} + s_{2f} = \frac{2y_0}{1+\gamma} - \frac{2c + r_{1c} + r_{2c}}{1+\gamma}$$

We first analyze the impact of the different royalty systems on the total quantity of seed. This total quantity is maximum and equal to $\frac{2(y_0 - c)}{1+\gamma}$ at the first best level. All the royalty systems lead to lower levels because the royalties on CS are positive in all cases. Among these systems, the base case (B) corresponds to the second best level in terms of total quantity of seed because the absence of a royalty on FSS leads to the lowest royalty level on CS. The ranking of the other systems depends on the cost parameters c and f (see Appendix B.1 for details). Notice that all the systems in which the royalties on CS and FSS are fully defined by the seed companies (A, C and P) lead to the same royalty level for CS and, thus, to the same total quantity of seed.

[18] This demand system is defined by maximizing the farmer surplus (Equation 3) with respect to s_{1c}, s_{1f}, s_{2c} and s_{2f}, with given royalty levels. Compared to the case with a covered market, we no longer have $s_{2f} = 1 - s_{1c} - s_{2c} - s_{1f}$.

We now compare the impact of royalty systems on total welfare. Welfare increases with total quantity, but it also depends on the proportion of CS and FSS because their production costs differ. The ranking of the royalty systems is summarized in the following proposition:

Proposition 2. *With no research, varieties performing equivalently ($\Delta = 0$) and a market that is not covered, no royalty system is able to reach the first best level.*

The UK system is the second best. The third best is the base case (with no royalty on FSS) if $\gamma > 2/3$ or $c > \frac{3\gamma-2}{2+\gamma}$ or $f < \frac{2(1-\gamma^2)(1+\gamma)}{(2-\gamma)(3\gamma-2)}$, and the Australian system is otherwise.

The ranking of the royalty systems results from two effects, namely, the effect related to the total quantity of seed on the one hand and the effect of seed production efficiency described previously on the other hand. As shown above, the total quantity is the highest with the base case system. However, as shown in Lemma 1, the proportion of FSS is excessive in the base case, leading to additional seed production costs. In the UK system, the regulator chooses a positive royalty on FSS, which leads to a better seed production efficiency.[19] The comparison with the other systems is detailed in Appendix B.2. The third best is either case B or A. System A leads to higher welfare compared to B if γ is high, c is small and f is high. Indeed, with a low level of c and a high level of f, the inefficiency related to the excessive quantity of FSS with B is stronger. In addition, with Bertrand competition, prices are lower and close to each other with a higher level of γ, so that only the seed production inefficiency effect remains.

3.3 Incentives to innovate (endogenous value of y_i)

We suppose now that each breeder has the capacity to increase the performance of the seed level from common level y_0 to a level y_i with $y_i = y_0 + k_i$. k_i is the innovation level embedded in the seed variety i. The research cost leading to this innovation level is supposed to be quadratic: $\frac{\alpha k_i^2}{2}$. α is a research cost parameter, and we suppose that it is sufficiently high. ($\alpha > \frac{1}{9(1-\gamma)}$) to guarantee profit concavity and duopoly equilibrium. The analysis below can be formulated in terms of either research investment or innovation level because the concepts are positively related. We choose the more common formulation in terms of research investment, but it is sufficient to establish this property by comparing innovation levels k_i.

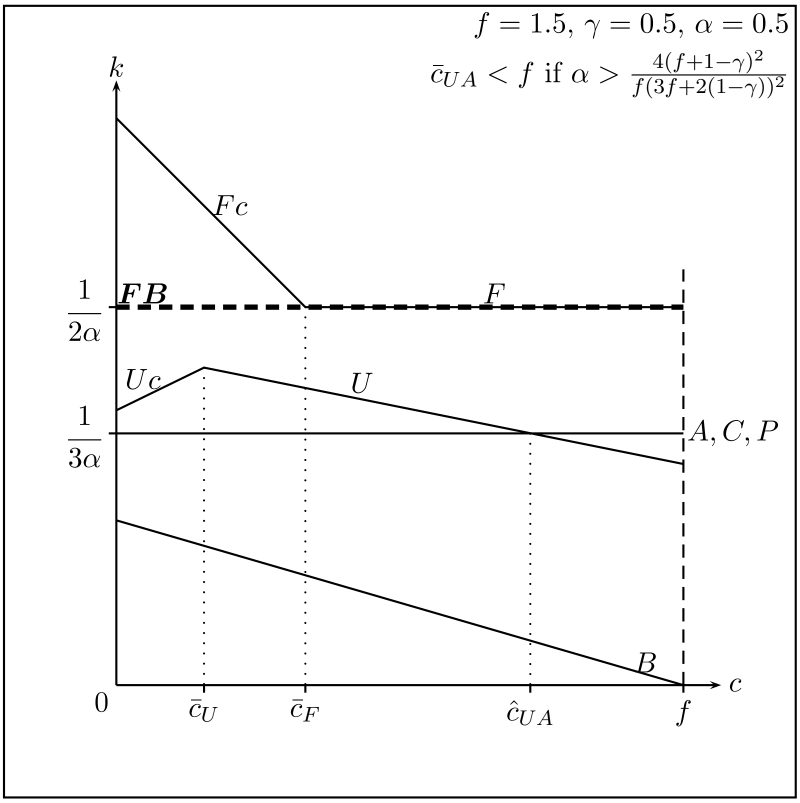
[19] Note that, in the UK system, the seed companies react to the positive royalty on FSS by increasing their royalty on CS (compared to the B case). Hence, $r_{ic}^U > r_{ic}^B$. However, the difference in the royalty level between CS and FSS is lower in the UK system ($r_{ic}^U - r_{if}^U < r_{ic}^B - r_{if}^U = r_{ic}^B$), leading to a quantity of FSS that is closer to the first best level. One can also observe that if the welfare was higher with no royalty on FSS, then the regulator in the UK system would choose $r_{if}^U = 0$, which would be equivalent to the nase case.

We analyze the impact of the royalty systems first on the research investment and second on the total welfare level.

Lemma 3. *With a covered market, the French system leads to the first best research investment if the CS production cost is high enough ($c > \hat{c}_F$); otherwise, it leads to excessive research investment.*

All the other royalty systems lead to insufficient research investment compared to the first best situation. Among them, the UK system leads to the highest research investment if c or α are not too high. Otherwise, the highest research investment is made in the competitive, Australian or prohibitive system, (all three leading to the same research investment). The base case system with now royalties on FSS always leads to the lowest research investment.

Figure 3: Comparison of research investment with a covered market



The detailed compilation of the innovation level, as well as the comparison between these levels, are given in Appendix C.1. Figure 3 illustrates lemma 3.

The French royalty system is the one that leads to the highest investment because this case is the one where the seed companies appropriate the highest share of total surplus due to their cooperation in fixing the CS royalty rate. For $c > \bar{c}_F$, the regulator, by defining $r_{\cdot f}$, can lead the seed companies to choose a research investment equal to the first best level. In other words, increasing $r_{.f}$ enables the regulator to increase the share of total surplus earned by seed companies so that they increase their investment up to the first best level. For $c < \bar{c}_F$, the seed companies invest too much compared to the first best level. Indeed, in this case, the marginal gain of each seed company from increasing its innovation level is higher than the increase in total welfare gain.[20] Since $r_{.f}$ cannot be negative, the regulator has no way to correct this problem.

Research investments for cases A, P and C are independent from the seed cost parameters c and f. This result is due to the assumption that the market is covered. With this assumption, seed cost parameters affect the quantity of CS but not the total demand for each seed. Moreover, the royalty rates are identical between FSS and CS in case A, only defined for CS in case P and with a difference that does not depend on the innovation level in case C. As a consequence, the marginal effect of research investment on gross profit is identical in the three cases, leading to the same investment level.

Research investment in case B is the lowest among all royalty systems because this case is the only one where the seed company profit only comes from CS. The innovation decreases with c because an increase in c makes CS less competitive than FSS, leading to a lower quantity of CS, lower gross profit for the seed companies and consequently lower innovation levels. Following the same logic, an increase in f leads to higher gross profit and consequently higher investment.

Case U shares some similarities with case B because, in both cases, seed companies competitively define the royalty rate only on CS. Case U leads to higher profit because of the positive royalty rate on FSS, which also leads to higher equilibrium rates on CS. An interior solution for the research investment is obtained if c is sufficiently high ($c > \bar{c}_U$). For the same reason as that described in case B, the investment level with this interior solution decreases with c (and increases with f). The research investment obtained in case U is higher compared to that in B and lower compared to that in F. However, it can be lower than that in A, P and C if $c > \hat{c}_{UA}$ and α sufficiently high.[21] The quantity of FSS decreases with the royalty rate of FSS, and this quantity is positive only if c is high enough ($c > \bar{c}_U$). If $c \leq \bar{c}_U$, then the regulator can no longer define a royalty rate on FSS that leads to maximum total welfare (case U_c); thus, he or

[20]This result is consistent with the IO literature on the incentives to innovate, which shows that overinvestment in research can occur in patent race models where the "winner-takes-all" (Belleflamme and Peitz, 2015, pp. 515-517) or in models with product differentiation, as we consider herein, with sufficiently smooth competition, such as Cournot competition (Vives, 2008, p. 433).

[21]More precisely, $k_i^U > \frac{1}{3\alpha}$ if $c < \hat{c}_{UA}$ if $\alpha > \frac{4(f+1-\gamma)^2}{f(3f+2(1-\gamma))^2}$ with $\hat{c}_{UA} = \frac{1}{3}(f + \frac{2}{\alpha} - \frac{f^2}{1+f-\gamma} - \frac{2f}{\alpha(2+3f-\gamma)})$. Note that this threshold on α can be greater than $\frac{1}{9(1-\gamma)}$.

she is constrained to define the maximum rate leading to no FSS. With this corner solution, the research investment increases with c because this leads to higher royalty rates and higher seed company profit.

We now compare the welfare level between the different systems. This comparison aggregates the seed production efficiency (Lemma 1) on the one hand and the impact on research investment (Lemma 3) on the other hand.

Proposition 3. *With a covered market and endogenous innovation level, the second best situation is either the UK, Australian or the French system.*

The Australian system obtains the second best outcome with a sufficiently high research cost (α). Otherwise, with low enough research cost, the second best outcome is obtained with the UK system if the CS production cost is low or, conversely, with the French system if the CS production cost is high.

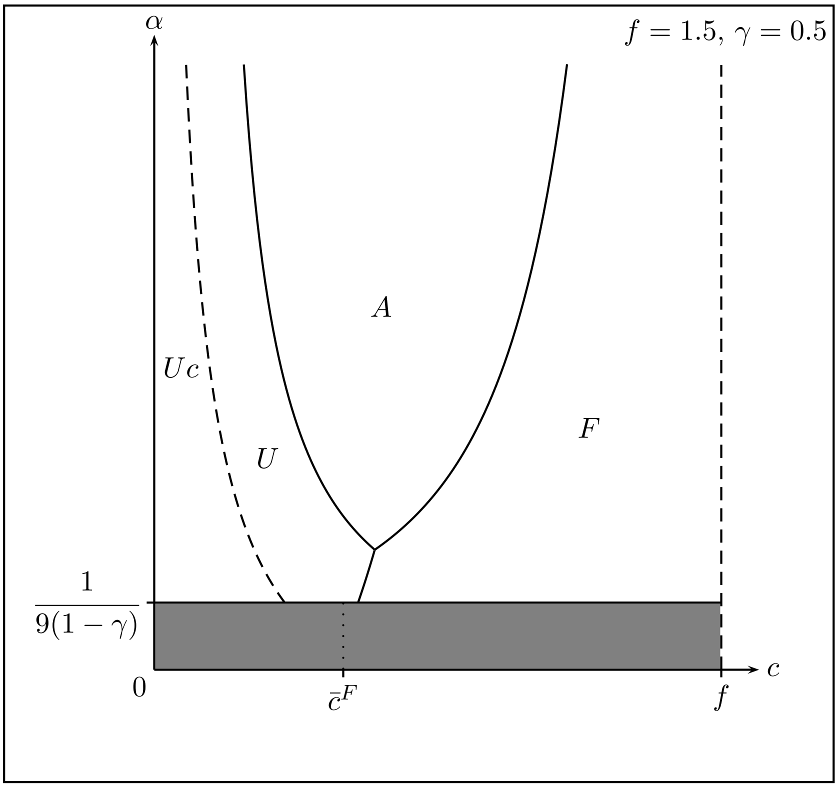
The detailed compilation of welfare level, as well as the comparison between these levels, are given in Appendix C.2. Figure 4 illustrates[22] Proposition 3. The ranking of the different systems with respect to CS production cost c (horizontal axis) can be explained by the share of CS *vs.* FSS: systems with a higher share of CS are more interesting with a low CS production cost, while systems with a higher share of FSS are more interesting with a high CS production cost. Since $s_{if}^U < s_{if}^A < s_{if}^F$, as c increases from 0 to f, the best royalty system is the UK system, then the Australian system and, last, the French system[23]. The ranking of the Australian *vs.* UK or French system with respect to the research cost parameter α (vertical axis) can be explained by the magnitude of the incentive effect described in Lemma 3 and illustrated in Figure 3. This effect is more important with a low value of α, and the best systems are thus those that lead to the highest research investment (F and UK). Conversely, with a high value of α, the research investment is small, which gives more weight to seed production efficiency, explaining why the Australian system performs better (cf. Lemma 1). Hence, as α increases, this system becomes more interesting compared to either U or F.

Our analysis in this section has been conducted under the assumption of a covered market. Proposition 3 aggregates the effects related to research incentives (Lemma 3) and production

[22]The comparison of the welfare levels between the different systems requires consideration of both interior and corner solutions for systems U and F. Figure 4 corresponds to a case where Fc – the corner solution with system F – is always dominated. In Appendix C.2, we also provide an illustration of the case where Fc can be the second best situation. Proposition 3 and the interpretation given herein are valid in both cases.

[23]We indeed have $s_{if}^U < s_{if}^A < s_{if}^F$ because $r_{ic}^U > r_{.f}^U$, $r_{ic}^A > r_{if}^A$ and $r_{ic}^F < r_{.f}^F$.

Figure 4: Second best with innovation and a covered market



efficiency (Lemma 1). However, integrating the effect on the total quantity (cf. Proposition 2) requires analyzing the research incentive in a context with a noncovered market. The results with this model are summarized in Appendix D. Part of Proposition 3 is still valid: the second best situation corresponds to cases U, A and F, with case U being more efficient with a low value of c and F being more efficient with a high value of c. However, case A does not necessarily emerge as the most efficient for high research cost α. In some cases, comparisons can only be made using numerical simulation because of the complexity of the solutions that are compared.

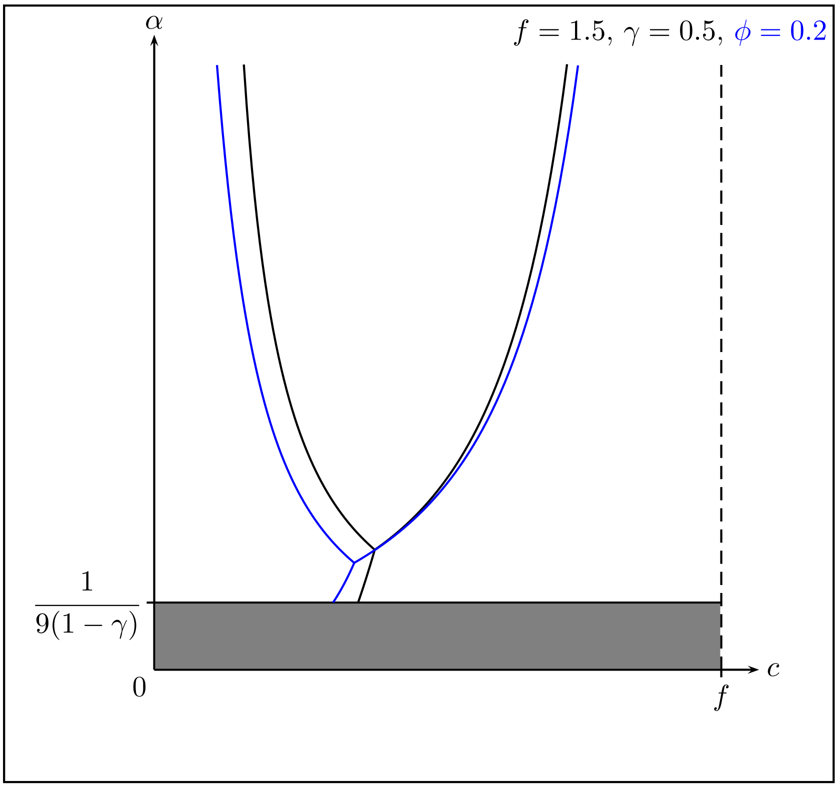
4 Discussion/Extension

Our analysis is conducted under the assumption that all decision-makers have perfect information regarding the parameters of the model. This assumption can be particularly strong when considering the decision of the regulator. This is more precisely the case when the regulator has to decide a certain level of the royalty rate on FSS (cases U and F) because this rate requires the regulator to know seed product costs and research costs. In other words, if information asymmetry between the regulator and the seed company was to be taken into account, then the equilibrium for a given value of royalty defined by the regulator would be different, leading to lower total welfare. Developing a more realistic version of the model with information asymmetry and appropriate regulation is beyond the scope of this paper. However, one can illustrate the impact of this information asymmetry by supposing that, in cases A and F, the regulator chooses a suboptimal level of royalty rate. More precisely, we constrain the regulator to choose $\tilde{r}^K_{.f} = (1 - \phi) \cdot r^K_{.f}$ (with $K = U, F$), with $r^K_{.f}$ being the solution compiled in the previous sections (with perfect information) and ϕ being the magnitude of the suboptimality. Figure 5 illustrates this comparison in the case with innovation and a covered market. As expected, we can then observe a larger zone where the second best situation corresponds to the Australian system because this system does not require any information on the regulator side. However, the general properties summarized in Proposition 3 are still valid.

The regulator may also be constrained to choose a suboptimal FSS royalty rate for reasons other than information asymmetry. In particular, if the regulator wants to set up a royalty on FSS starting from a situation where such a royalty does not exist, he or she might face the opposition of farmers because in the short term, they will lose from such a measure. Hence, a suboptimal FSS royalty rate can also be the only feasible political compromise among stakeholders. This is specifically true in Europe, where European regulation requires member states to create a national system of "equitable remuneration" for breeders. Many countries have set the royalty rate on FSS at a percentage of the royalty rate on CS (e.g., 50% in Germany). Other countries have decided to establish a single royalty for each species on FSS (negotiated or not); however, these royalties are always set at a lower level than those on CS. In contrast to our model, where it may be rational under certain conditions to set a royalty on FSS at a higher level than the royalty on CS, in the real world, this policy would not be accepted by farmer representatives. This puts at a disadvantage the French and English cases, where there is a collective decision made regarding the level of the royalty, in contrast to the Australian case where firms are only constrained to set the same royalty on FSS and SC.

This model can also be used to analyze the interest in switching from an inbred line to a hybrid seed. Such a switch has been observed for some open-pollinated species, such as rapeseed or sunflower. For self-pollinated species, some breeding companies have been investing in developing hybrid seeds for several decades, leading to some fraction of hybrid seeds in some cases (e.g., wheat and barley in France). In our model, switching to hybrid seeds would correspond

Figure 5: Second best with suboptimal decision of the regulator in cases U and F



to a switch toward a case where the farmer can no longer produce FSS (i.e., prohibition case). However, switching to hybrid seed also leads to an increase in the CS production cost because the CS production yield is lower with hybrid seeds, and hybrid production requires extra operations and control to obtain male-sterile plants. If we ignore the impact on research investment, we can observe that the prohibition case is far from being the most valuable. A higher CS production cost makes this disadvantage even stronger. However, this disadvantage can be compensated if yields are higher with hybrid seeds. Moreover, yield superiority needs to be even higher when comparing to the cases where there is some royalty on FSS because we have shown that these systems are more efficient. In other words, introducing a royalty in FSS makes hybrid seed less interesting from a social welfare perspective. This result is in line with Ambec et al. (2008). This result is still valid if the impact on research investment is taken into account. In this case, hybrid seeds can only be more interesting collectively if they lead to a sufficiently high increase in research efficiency compared to inbred lines (lower research cost parameter α). Indeed, this increase in research efficiency has to compensate for the higher production cost.

5 Conclusion

This article analyzes the economic impact of the existence of farm-saved seed (FSS) for some self-pollinated crops, such as wheat. FSS has the characteristic of being produced efficiently in at least some situations. However, it may decrease the benefit that a breeder can obtain from commercializing its new varieties, leading to lower research investment. In this article, we compare six different stylized royalty systems that are representative of the diversity of systems that can be observed worldwide. Royalties can be defined on certified seed (CS) sold to farmers or on FSS, as it is the case in different countries worldwide. We show that having some FSS is welfare improving in cases where a royalty can be set on FSS. We also show that there is an interest in regulating royalty levels, either by constraining the royalty to be equal between FSS and CS (Australian system) or by having the royalty on FSS defined by a regulator (French or UK system). These results are valid in different scenarios either with a given level of performance of seed varieties or with endogenous performance level defined by the R&D decision of the competing breeders.

One may observe that these results depend on the assumption we make regarding seed production cost. More precisely, we suppose that while the first unit of FSS is produced more efficiently compared to that of CS, the marginal cost of FSS becomes higher compared to CS when more farmers produce FSS. This assumption is consistent with the fact that we have both FSS and CS in some countries where royalty levels on FSS and CS are similar so that farmers' trade-off is mainly related to seed cost (see Table 1). However, an empirical analysis of the seed production process and cost would be very useful to define, in a given situation, the most accurate royalty system. For instance, CS transportation costs may be rather different depending on country size, and we expect this parameter to influence the best royalty system in different situations. The analysis of seed production cost may also be very relevant in examining the interest in hybrid seeds.

In this paper, we have considered a context where breeding research is carried out by competing firms. These firms define all decisions related to research investment. However, it would also be interesting to compare this context with alternative mechanisms for funding and defining the orientation of research, such as prizes or research contracts (see Clancy and Moschini, 2013, for a review of these different mechanisms).

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Appendix

A Covered market without investment in R&D

A.1 Equilibrium values

A.1.1 Base case

At the third stage, breeders compete in prices. They choose their optimal royalty by maximizing their profit. Since there is no royalties on FSS, their profit only depends on the quantity of CS chosen by farmers as follows

$$\pi_i(r_i, r_j) = r_{ic} * s_{ic}(r_{ic}, r_{jc}, r_{if}) \quad with \quad i = \{1, 2\} \quad and \quad i \neq j \tag{6}$$

The demands, $s_{ic}(.)$, follow the system (4) for $r_{if} = 0$. The maximization of the profit equations (6) with respect to r_{ic} leads to

$$r_{1c}^B = \frac{(f-c)(1-\gamma)}{2(1-\gamma)+f} + \frac{f\Delta}{2(1-\gamma)+3f}$$
$$r_{2c}^B = \frac{(f-c)(1-\gamma)}{2(1-\gamma)+f} - \frac{f\Delta}{2(1-\gamma)+3f},$$

with $\Delta = y_1 - y_2$ and $y_i = y_0 + k_i$. From the optimal royalties r_{ic}^B we obtain

$$s_{1c}^B = \frac{1}{2} - \frac{c}{2f} - \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} + \frac{(1-\gamma+f)\Delta}{(2(1-\gamma)+3f)(1-\gamma)}$$
$$s_{2c}^B = \frac{1}{2} - \frac{c}{2f} - \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} - \frac{(1-\gamma+f)\Delta}{(2(1-\gamma)+3f)(1-\gamma)}$$

$$s_{1f}^B = \frac{c}{2f} + \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} + \frac{\Delta}{(2(1-\gamma)+3f)}$$
$$s_{2f}^B = \frac{c}{2f} + \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)} - \frac{\Delta}{(2(1-\gamma)+3f)}$$

$$\Pi_1^B = \frac{(1-\gamma)(f-c)^2(1+f-\gamma)}{2f(2+f-2\gamma)^2} + \frac{(f-c)(1+f-\gamma)\Delta}{(2+f-2\gamma)(2+3f-2\gamma)} + \frac{f(1+f-\gamma)\Delta^2}{2(1-\gamma)(2+3f-2\gamma)^2}$$

$$W^B = \frac{y_1+y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} - \frac{(f-c)^2(1-\gamma)^2}{2f(2(1-\gamma)+f)} + \frac{\Delta^2}{4(1-\gamma)} - \frac{f(1-\gamma+2f)}{2(1-\gamma)(2-2\gamma+3f)^2}.\Delta^2$$

Positive demands are obtained under this following condition

$$s_{2c}^B \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^B \quad \text{with :} \quad \bar{\Delta}^B = \frac{f-c}{f} \cdot (1-\gamma) \cdot \underbrace{\left(\frac{2(1-\gamma)+3f}{2(1-\gamma)+f}\right)}_{>1}$$

A.1.2 Prohibition system

In the prohibition system, the breeders' profit is similar to the profit of Equation (6). The demands, $s_{ic}(.)$, follow the system (4) for $r_{if} = +\infty$ and $s_{if} = 0$. The maximization of the profit equation (6) with respect to r_{ic} leads to

$$r_{1c}^P = 1 - \gamma + \frac{\Delta}{3} \quad ; \quad r_{2c}^P = 1 - \gamma - \frac{\Delta}{3}$$

From the optimal royalty r_{ic}^P we obtain

$$s_{1c}^P = \frac{1}{2} + \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{2c}^P = \frac{1}{2} - \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{1f}^P = s_{2f}^P = 0$$

$$\Pi_1^P = \frac{(3 - 3\gamma + \Delta)^2}{18(1-\gamma)}$$

$$W^P = \frac{y_1 + y_2}{2} - c - \frac{1+\gamma}{4} + \frac{\Delta^2}{4(1-\gamma)} - \frac{\Delta^2}{9(1-\gamma)}$$

Positive demands are obtained under this following condition

$$s_{2c}^P \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^P \quad \text{with :} \quad \bar{\Delta}^P = 3 \cdot \frac{f-c}{f} \cdot (1-\gamma)$$

A.1.3 Competition system

In the competition system, there is a tariff on FSS. Thus the profit of breeder i depends also on the demand of FSS as follows

$$\pi_i = r_{ic} s_{ic}(r_{ic}, r_{jc}, r_{if}) + r_{if} s_{if}(r_{ic}, r_{if}) \tag{7}$$

The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). The maximization of the profit equation (7) with respect to r_{ic} and r_{if} leads to

$$r_{1c}^A = 1 - \gamma + \frac{\Delta}{3} \quad ; \quad r_{2c}^A = 1 - \gamma - \frac{\Delta}{3} \quad ;$$

$$r_{1f}^A = 1 - \gamma + \frac{c}{2} + \frac{\Delta}{3} \quad ; \quad r_{2f}^A = 1 - \gamma + \frac{c}{2} - \frac{\Delta}{3} \quad ;$$

From the optimal royalties r_{ic}^C and r_{if}^C we obtain

$$s_{1c}^C = \frac{1}{2} - \frac{c}{4f} + \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{2c}^C = \frac{1}{2} - \frac{c}{4f} - \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{1f}^C = s_{2f}^C = \frac{c}{4f}$$

$$\Pi_1^C = \frac{(3 - 3\gamma + \Delta)^2}{18(1-\gamma)} + \frac{c^2}{8f}$$

$$W^C = \frac{y_1 + y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} - \frac{c^2}{8f} + \frac{\Delta^2}{4(1-\gamma)} - \frac{\Delta^2}{9(1-\gamma)}$$

Positive demands are obtained under this following condition

$$s_{2c}^C \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^C \quad \text{with :} \quad \bar{\Delta}^C = \frac{f-c}{f} \cdot (1-\gamma) \cdot \underbrace{\left(\frac{3(2f-c)}{2(f-c)}\right)}_{>1}$$

A.1.4 Australian system

In the Australian system, royalties on CS and FSS have to be equal such as $r_{ic} = r_{if} \equiv r_{i.}$. As a consequence, the profit function is simplified as follows

$$\pi_i = r_{i.} * (s_{ic}(r_{i.}, r_{j.}) + s_{if}(r_{i.})) \tag{8}$$

The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). The maximization of the profit equation (8) with respect to $r_{i.}$ leads to

$$r_{1c}^A = r_{1f}^A = 1 - \gamma + \frac{\Delta}{3} \quad ; \quad r_{2c}^A = r_{2f}^A = 1 - \gamma - \frac{\Delta}{3} \quad ;$$

From the optimal royalties $r_{i.}^A$ we obtain

$$s_{1c}^A = \frac{1}{2} - \frac{c}{2f} + \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{2c}^A = \frac{1}{2} - \frac{c}{2f} - \frac{\Delta}{6(1-\gamma)} \quad ; \quad s_{1f}^C = s_{2f}^C = \frac{c}{2f}$$

$$\Pi_1^A = \frac{(3 - 3\gamma + \Delta)^2}{18(1-\gamma)}$$

$$W^A \frac{y_1 + y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} + \frac{\Delta^2}{4(1-\gamma)} - \frac{\Delta^2}{9(1-\gamma)}$$

Positive demands are obtained under this following condition

$$s_{2c}^A \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^A \quad \text{with :} \quad \bar{\Delta}^A = 3 \cdot \frac{f-c}{f} \cdot (1-\gamma)$$

A.1.5 UK system

In the UK system, the regulator chooses, at the first stage, the same royalty rate on FSS for both breeders. The profit of each breeder becomes

$$\pi_i = r_{ic} s_{ic}(r_{ic}, r_{jc}, r_{.f}) + r_{.f} s_{if}(r_{ic}, r_{.f}) \tag{9}$$

The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). The maximization of the profit equation (9) with respect to r_{ic} leads to

$$\bar{r}_{ic}(r_{.f}) = \frac{(1-\gamma)(f - c + 2r_{.f})}{2(1-\gamma) + f}$$

Substituting the royalties $\bar{r}_{ic}(r_{.f})$ into the profit (9) leads to the profit $\bar{\pi}_i(k_i, k_j)$. At stage 1, the regulator maximize the welfare, $\overline{W} = \overline{FS} + \sum_i^2 \bar{\pi}_i$, with respect to $r_{.f}$. The resolution of the stage 1 yields to the optimal royalty rate

$$r_f^U = \frac{(1-\gamma)(f-c)}{f}$$

From the optimal royalties $r^U_{.f}$ we obtain

$$r^U_{1c} = \frac{(1-\gamma)(f-c)}{f} + \frac{f\Delta}{2(1-\gamma)+3f} = r^U_f + \frac{f\Delta}{2(1-\gamma)+3f}$$
$$r^U_{2c} = \frac{(1-\gamma)(f-c)}{f} - \frac{f\Delta}{2(1-\gamma)+3f} = r^U_f - \frac{f\Delta}{2(1-\gamma)+3f}$$

$$s^U_{1c} = \frac{1}{2} - \frac{c}{2f} + \frac{(1-\gamma+f)\Delta}{2(2(1-\gamma)+3f)(1-\gamma)}$$
$$s^U_{2c} = \frac{1}{2} - \frac{c}{2f} - \frac{(1-\gamma+f)\Delta}{2(2(1-\gamma)+3f)(1-\gamma)}$$

$$s^U_{1f} = \frac{c}{2f} + \frac{\Delta}{2(2(1-\gamma)+3f)} \quad ; \quad s^U_{2f} = \frac{c}{2f} - \frac{\Delta}{2(2(1-\gamma)+3f)}$$

$$\Pi^U_1 = \frac{(1-\gamma)(f-c)}{2f} + \frac{\Delta(f-c)(1+f-\gamma)}{f(2+3f-2\gamma)} + \frac{\Delta^2 f(1+f-\gamma)}{2(1-\gamma)(2+3f-2\gamma)^2}$$

$$W^U = \frac{y_1+y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} + \frac{\Delta^2}{4(1-\gamma)} - \frac{f(1-\gamma+2f)}{2(2(1-\gamma)+3f)^2(1-\gamma)} \cdot \Delta^2$$

Positive demands are obtained under this following condition

$$s^U_{2c} \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^U \quad \text{with :} \quad \bar{\Delta}^U = \frac{f-c}{f} \cdot (1-\gamma) \cdot \underbrace{\left(\frac{2(1-\gamma)+3f}{1-\gamma+f}\right)}_{>1}$$

A.1.6 French system

In the French system, the regulator chooses, at the first stage, the same royalty rate on FSS for both breeders as in the UK system. The difference is during the third stage where a private organization, including both firms, maximizes the joint profit of both firms by a single royalty $r_{.c}$. The joint profit is

$$J = \sum_{i=1}^{2} \pi_i \tag{10}$$

where $\pi_i = r_{.c}s_{ic}(r_{.c}, r_{.f}) + r_{.f}s_{if}(r_{.c}, r_{.f})$. The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). The maximization of the joint profit equation (10) with respect to $r_{.c}$ leads to

$$\bar{r}_{.c}(r_{.f}) = \frac{(f-c)}{2} + r_{.f}$$

Substituting the royalties $\bar{r}_{.c}(r_{.f})$ into the joint profit (10) leads to the joint profit $\overline{J}$. At stage 1, the regulator maximize the welfare, $\overline{W} = \overline{FS} + \overline{J}$, with respect to $r_{.f}$. The resolution of the stage 1 yields to no optimal value for the royalty rate on FSS. Indeed, the royalty on FSS, $r^F_{.f}$, could be equal to 0 or capture the whole farmer's surplus, it has no impact on the welfare.

We show the results with the french system for $r^F_{.f} = 0$

$$r^F_{1c} = r^F_{2c} = \frac{f-c}{2}$$

$$s^F_{1c} = \frac{1}{2} - \frac{c+f}{4f} + \frac{\Delta}{2(1-\gamma)} \quad ; \quad s^F_{2c} = \frac{1}{2} - \frac{c+f}{4f} - \frac{\Delta}{2(1-\gamma)} \quad ; \quad s^F_{1f} = s^F_{2f} = \frac{c+f}{4f}$$

$$\Pi^F_1 = \frac{(f-c)^2}{8f}$$

$$W^F = \frac{y_1+y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} - \frac{(f-c)^2}{8f} + \frac{\Delta^2}{4(1-\gamma)}$$

Positive demands are obtained under this following condition

$$s^F_{2c} \geq 0 \quad \Leftrightarrow \quad \Delta < \bar{\Delta}^F \quad \text{with :} \quad \bar{\Delta}^F = \frac{1}{2} \cdot \frac{f-c}{f} \cdot (1-\gamma) \cdot$$

A.1.7 Fully regulated pricing system (First Best)

When the tariff is fully regulated, there is no longer third stage, the profit of breeders i becomes

$$\pi_i = r_{.c} s_{ic}(r_{.c}, r_{.f}) + r_{.f} s_{if}(r_{.c}, r_{.f}) \tag{11}$$

The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). At stage 1, the regulator maximizes the welfare with respect to the royalty rates on CS and on FSS, $r_{.c}$ and $r_{.f}$

$$r^{FB}_{.c} = \{0; r^{FB}_{.f}\} \quad ; \quad r^{FB}_{.f} = \{0; r^{FB}_{.c}\}.$$

To be optimal, royalties on CS and FSS have to be equal, they can be set at 0 or at the maximal value that monopolizes the farmers' surplus. Setting $r^{FB}_{.c} = r^{FB}_{.f} = 0$, we obtain

$$s^{FB}_{1c} = \frac{1}{2} - \frac{c}{2f} + \frac{\Delta}{2(1-\gamma)} \quad ; \quad s^{FB}_{2c} = \frac{1}{2} - \frac{c}{2f} - \frac{\Delta}{2(1-\gamma)} \quad ; \quad s^{FB}_{1f} = s^{FB}_{2f} = \frac{c}{2f}$$

$$W^{FB} = \frac{y_1+y_2}{2} - c - \frac{1+\gamma}{4} + \frac{c^2}{2f} + \frac{\Delta^2}{4(1-\gamma)}$$

A.2 Proof of Proposition 1

The welfare comparison is only made for duopoly equilibrium, which requires to have $\Delta < \bar{\Delta}^K$ (with $K = FB, B, P, \dots$). The lowest level of $\bar{\Delta}^K$ is $\bar{\Delta}^F$. Therefore, comparisons are made under the assumption that $\Delta < \bar{\Delta}^F$, which is the most restrictive condition.
When comparing the welfare level between the different system we have:

1. For any Δ, we have $W^A > W^C > W^P$.
2. For $\Delta = 0$, we have $W^{FB} = W^U = W^A$, but for $\Delta > 0$, we have $W^{FB} > W^U > W^A$.
3. For $\Delta = 0$ we have $W^F < W^{FB}(= W^U = W^A)$. However, W^F increases more drastically with Δ compared to W^U and W^A. We can first show that $W^U > W^F$ if $\Delta < \bar{\Delta}^F$ because:

$$W^U > W^F \quad \Leftrightarrow \quad \Delta < \underbrace{\frac{f-c}{2f} \cdot (1-\gamma)}_{=\bar{\Delta}^F} \cdot \underbrace{\sqrt{\frac{(2(1-\gamma)+3f)^2}{(1-\gamma+2f)(1-\gamma)}}}_{>1}$$

When comparing W^A and W^F, we get:

$$W^A > W^F \quad \Leftrightarrow \quad \Delta < \underbrace{\frac{f-c}{2f}\cdot(1-\gamma)\cdot}_{=\bar{\Delta}^F} \underbrace{\sqrt{\frac{9f}{2(1-\gamma)}}}_{<1 \text{ if } f<2(1-\gamma)/9}$$

Hence we may have $W^F > W^A$ if $f < 2(1-\gamma)/9$ and with high enough values of Δ.

B Noncovered market without investment in R&D

B.1 Equilibrium values

The three following tables show the results for a non-covered market and varieties performing equivalently ($\Delta = 0$) without investment in R&D, as a consequence, the only change compared to the Appendix A.1 is the demand system 5. More specifically, table 4 shows results for the first best and the base case without royalties on FSS, table 5 presents the results for the Prohibition, the Competition and the Australian systems and, finally table 6 shows the results for regulated royalties system namely the French and the UK systems.

Table 4: Results for the First Best and the base system

	First Best (FB)	Base Case (B)
s_{ic}	$\frac{y_0-c}{1+\gamma} - \frac{c}{2f}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)} - \frac{c}{4f} - (\frac{\gamma}{2-\gamma})\frac{2y_0(1-\gamma)+c\gamma}{4(1+f(2-\gamma)-\gamma^2)}$
s_{if}	$\frac{c}{2f}$	$\frac{2y_0(1-\gamma)+c\gamma}{4(1+f(2-\gamma)-\gamma^2)} + \frac{c}{4f}$
s_i	$\frac{y_0-c}{1+\gamma}$	$\frac{2y_0(1+f-\gamma^2)-c(1+2f-\gamma^2)}{2(1+f(2-\gamma)-\gamma^2)(1+\gamma)}$
r_{ic}	0	$\frac{2fy_0(1-\gamma)+cf\gamma}{2(1+f(2-\gamma)-\gamma^2)} - \frac{c}{2}$
r_{if}	0	.
Π	0	$\frac{(1-\gamma)(1+2f-\gamma^2)(2fy_0-c(1+2f+\gamma))^2}{8f(1+\gamma)(1+f(2-\gamma)-\gamma^2)^2}$
W	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f}$	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f} - (1-\gamma)\frac{2f+1+\gamma}{2f+1-\gamma^2}\cdot\Pi_i^B$

Table 5: Results for the Prohibition, Competition and Australian systems

	Prohibition (P)	Competition (C)	Australian (A)
s_{ic}	$\frac{y_0-c}{(2-\gamma)(1+\gamma)}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)} - \frac{c}{4f}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)} - \frac{c}{2f}$
s_{if}	.	$\frac{c}{4f}$	$\frac{c}{2f}$
s_i	$\frac{y_0-c}{(2-\gamma)(1+\gamma)}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)}$
r_{ic}	$\frac{(y_0-c)(1-\gamma)}{2-\gamma}$	$\frac{(y_0-c)(1-\gamma)}{2-\gamma}$	$\frac{(y_0-c)(1-\gamma)}{2-\gamma}$
r_{if}	.	$\frac{(y_0-c)(1-\gamma)}{2-\gamma} + \frac{c}{2}$	$\frac{(y_0-c)(1-\gamma)}{2-\gamma}$
Π	$\frac{(y_0-c)^2(1-\gamma)}{(2-\gamma)^2(1+\gamma)}$	$\frac{(y_0-c)^2(1-\gamma)}{(2-\gamma)^2(1+\gamma)} + \frac{c^2}{8f}$	$\frac{(y_0-c)^2(1-\gamma)}{(2-\gamma)^2(1+\gamma)}$
W	$\frac{(y_0-c)^2}{1+\gamma} - (1-\gamma)\Pi_i^P$	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f} - (1-\gamma)\Pi_i^P - \frac{c^2}{8f}$	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f} - (1-\gamma)\Pi_i^P$

Table 6: Results for the French and the UK systems

	French (F)	UK (U)
$s_{ic}(r_f)$	$\frac{y_0-c}{2(1+\gamma)} - \frac{c}{4f}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)} - \frac{c}{4f} - (\frac{\gamma}{2-\gamma})\frac{2y_0(1-\gamma)+c\gamma-2r_f(2-\gamma)}{4f(1+f(2-\gamma)-\gamma^2)}$
$s_{if}(r_f)$	$\frac{2(y_0-2r_f)}{4(1+2f+\gamma)} + \frac{c}{4f}$	$\frac{2y_0(1-\gamma)+c\gamma-2r_f(2-\gamma)}{4f(1+f(2-\gamma)-\gamma^2)} + \frac{c}{4f}$
$r_{ic}(r_f)$	$\frac{fy_0+r_f(1+\gamma)}{1+\gamma+2f} - \frac{c}{2}$	$\frac{2fy_0(1-\gamma)+cf\gamma+2r_f(1-\gamma^2)}{2(1+f(2-\gamma)-\gamma^2)} - \frac{c}{2}$
s_{ic}	$\frac{y_0-c}{2(1+\gamma)} - \frac{c}{4f}$	$\frac{y_0-c}{(2-\gamma)(1+\gamma)} - \frac{c}{4f} - \frac{\gamma}{2-\gamma} \cdot \frac{4y_0(1-\gamma)^2+c(4-3\gamma)\gamma}{4f(2-\gamma)^2+8(1-\gamma)^2(1+\gamma})$
s_{if}	$\frac{c}{4f} + \frac{2y_0}{4(1+\gamma+2f)}$	$\frac{4y_0(1-\gamma)^2+c(4-3\gamma)\gamma}{4f(2-\gamma)^2+8(1-\gamma)^2(1+\gamma)} + \frac{c}{4f}$
s_i	$\frac{2y_0(1+f+\gamma)-c(1+2f+\gamma)}{(1+2f+\gamma)2(1+\gamma)}$	$\frac{2y_0(2(1-\gamma)^2(1+\gamma)+f(2-\gamma))-c(2+2f(2-\gamma)+3\gamma-(2-3\gamma)\gamma^2)}{2f(2-\gamma)^2(1+\gamma)+4(1-\gamma^2)^2}$
r_{ic}	$\frac{fy_0}{1+\gamma+2f} - \frac{c}{2}$	$\frac{2-\gamma}{\gamma} \cdot r_{if}^U$
r_{if}	0	$\frac{(1-\gamma)\gamma(2fy_0-c(1+2f+\gamma))}{(2f(2-\gamma)^2+4(1-\gamma)^2(1+\gamma))}$
Π	$\frac{(2fy_0-c(1+\gamma+2f))^2}{8f(1+\gamma)(1+\gamma+2f)}$	$\frac{(1-\gamma)(2fy_0-c(1+2f+\gamma))(2fy_0-c(2f+1-\gamma^2))}{4f(1+\gamma)(f(2-\gamma)^2+2(1-\gamma^2)^2)}$
W	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f} - \Pi_i^F$	$\frac{(y_0-c)^2}{1+\gamma} + \frac{c^2}{2f} - (1-\gamma)\frac{(1-\gamma)(2fy_0-c(1+2f+\gamma))^2}{4f(f(2-\gamma)^2(1+\gamma)+2(1-\gamma^2)^2)}$

B.2 Proof of Proposition 2

The necessary condition for positive demands and profits is

$$f > c \cdot \frac{1+\gamma}{2(y_0-c)}.$$

Note that since $f > c$, this constraint is binding if $1+\gamma > 2(y_0-c)$ which requires to have $c > y_0 - (1+\gamma)/2$.

The ranking of welfare is as follows

1. For any parameter values, no system reaches the first best.
2. For any parameter values, we have $W^A > W^C > W^P$.
3. Moreover, $W^B > W^F$ and $W^U > W^B$
4. $W^A > W^U$ for

$$f < \frac{c^2(2-\gamma)(1+\gamma)}{4(y_0-c)(2y_0(1-\gamma)-c(2+\gamma))}$$

   However this condition is never fulfilled for $f > c \cdot \frac{1+\gamma}{2(y_0-c)}$. Hence we always have $W^U > W^A$.

5. $W^B > W^A$ if $f > \hat{f}^{BA}$ with:

$$\hat{f}^{BA} = \frac{(1+\gamma)(c(3c-2y_0)(2-\gamma)^2 - 4(y_0-c)^2(1-\gamma)^2)}{4(y_0-c)(2-\gamma)(y_0(2-3\gamma)+c(2+\gamma))} - \frac{(1+\gamma)(2y_0(1-\gamma)+c\gamma)\sqrt{4(y_0-c)^2(1-\gamma)^2+c(2-\gamma)(4y_0-c(2+\gamma))}}{4(y_0-c)(2-\gamma)(y_0(2-3\gamma)+c(2+\gamma))}$$

$W^B > W^C$ if $f > \hat{f}^{BC}$ with:

$$\hat{f}^{BC} = \frac{2(1-\gamma^2)(2y_0(1-\gamma)^2 + c\gamma(3-2\gamma)}{(2-\gamma)(2y_0(5\gamma - 2 - 3\gamma^2) + c\gamma(5\gamma - 6))}$$

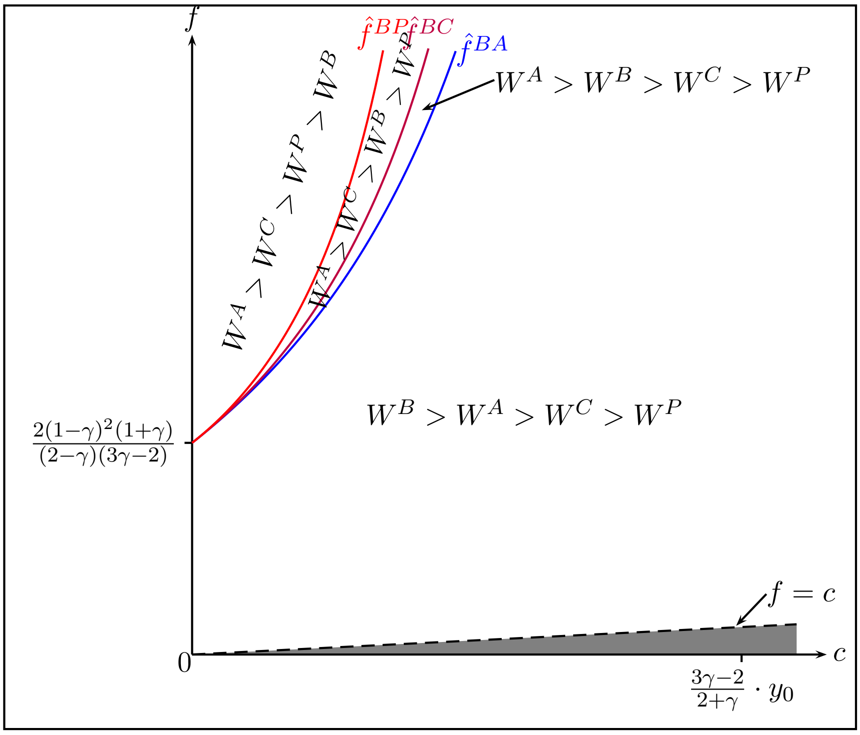
$W^B > W^P$ if $f > \hat{f}^{BP}$ with:

$$\hat{f}^{BP} = \frac{(1-\gamma^2)(4(y_0-c)^2(1-\gamma)^3 + c(2-\gamma)^2(c(5-\gamma) + 2y_0(1-\gamma)))}{4(2-\gamma)((y_0-c)^2(1-\gamma)^2(3\gamma-2) - c(2-\gamma)(2y_0(1-\gamma)^2 + c(2-\gamma^2)))}$$
$$+ \frac{(1-\gamma^2)(2y_0(1-\gamma) + c\gamma)\sqrt{4y_0^2(1-\gamma)^4 + y_0 c\gamma(1-\gamma)^2(3-2\gamma) + c^2(24 - \gamma(3-\gamma)(9+\gamma))}}{4(2-\gamma)((y_0-c)^2(1-\gamma)^2(3\gamma-2) - c(2-\gamma)(2y_0(1-\gamma)^2 + c(2-\gamma^2)))}$$

The threshold values $\hat{f}^{BA}$, $\hat{f}^{BC}$ and $\hat{f}^{BP}$ are illustrated in Figure 6. Note that, for $c = 0$, we have:

$$\hat{f}^{BA} = \hat{f}^{BC} = \hat{f}^{BP} = \frac{2(1-\gamma)^2(1+\gamma)}{(2-\gamma)(\gamma-2)}$$

Figure 6: Ranking of B with respect to A, C and P with no research and non covered market



C Covered market with investment in R&D

C.1 Equilibrium values

Here, the market is covered as in the Appendix A.1, therefore the game follows the demand system (4). There is a stage of investment decision before the price competition. In the case where the public authority chooses a regulated royalty, it is done before the choice of investment.

The first best is only based on the welfare maximization with respect to royalties, the investment decisions are still made by both firms. The results for the first best and the base case are presented in Table 7 and the results for the Prohibition, the Competition and the Australian system are presented in Table 8. The UK and French systems are more specific and thus presented in more details. Remind that the investment decision variable is k_i and plays on the yield variable $y_i = y_0 + k_i$ with a quadratic cost of $\frac{k_i^2}{2}$ in the breeders' profit.

Table 7: Results for the First Best and the base case

	First Best (FB)	Base case (B)
s_{ic}	$\frac{1}{2} - \frac{c}{2f}$	$\frac{1}{2} - \left(\frac{c}{2f} + \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)}\right)$
s_{if}	$\frac{c}{2f}$	$\frac{c}{2f} + \frac{(f-c)(1-\gamma)}{2f(2(1-\gamma)+f)}$
s_i	$\frac{1}{2}$	$\frac{1}{2}$
r_{ic}	$1-\gamma$	$\frac{(f-c)(1-\gamma)}{2+f-2\gamma}$
r_{if}	$1-\gamma$	0
k_i	$\frac{1}{2\alpha}$	$\frac{(f-c)(1+f-\gamma)}{\alpha(2+f-2\gamma)(2+3f-2\gamma)}$
Π	$\frac{1-\gamma}{2} - \frac{1}{8\alpha}$	$\frac{(f-c)(1+f-\gamma)\left(\frac{(f-c)(1-\gamma)}{f} - \frac{(f-c)(1+f-\gamma)}{\alpha(2+3-2\gamma)^2}\right)}{2(2+f-2\gamma)^2}$
W	$y_0 - c - \frac{1}{4} + \frac{c^2}{2f} - \frac{\gamma}{4} + \frac{1}{4\alpha}$	$y_0 - \frac{3c}{4} - \frac{1}{4} + \frac{3c^2}{8f} - \frac{\gamma}{4} - \frac{f}{8} + \frac{1}{8}(f-c)\left(\frac{c(1+f-\gamma)+f(3+f-3\gamma)}{\alpha f(2+f-2\gamma)^2} + \frac{c(1+f-\gamma)+f(5+7f-5\gamma)}{\alpha f(2+3f-2\gamma)^2} + \frac{(f-c)(4+f-4\gamma)}{(2+f-2\gamma)^2}\right)$

Table 8: Results for the Prohibition, Competition and Australian systems

	Prohibition (P)	Competition (C)	Australian (A)
s_{ic}	$\frac{1}{2}$	$\frac{1}{2} - \frac{c}{4f}$	$\frac{1}{2} - \frac{c}{2f}$
s_{if}	.	$\frac{c}{4f}$	$\frac{c}{2f}$
s_i	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
r_{ic}	$1-\gamma$	$1-\gamma$	$1-\gamma$
r_{if}	.	$1-\gamma+\frac{c}{2}$	$1-\gamma$
k_i	$\frac{1}{3\alpha}$	$\frac{1}{3\alpha}$	$\frac{1}{3\alpha}$
Π	$\frac{1-\gamma}{2} - \frac{1}{18\alpha}$	$\frac{1-\gamma}{2} + \frac{c^2}{8f} - \frac{1}{18\alpha}$	$\frac{1-\gamma}{2} - \frac{1}{18\alpha}$
W	$y_0 - c - \frac{1}{4} - \frac{\gamma}{4} + \frac{2}{9\alpha}$	$y_0 - c - \frac{1}{4} + \frac{3c^2}{8f} - \frac{\gamma}{4} + \frac{2}{9\alpha}$	$y_0 - c - \frac{1}{4} + \frac{c^2}{2f} - \frac{\gamma}{4} + \frac{2}{9\alpha}$

C.1.1 UK system

In the UK system, the regulator chooses, at the first stage, the same royalty rate on FSS for both breeders. The profit of each breeder becomes

$$\pi_i = r_{ic}s_{ic}(r_{ic}, r_{jc}, r_{.f}) + r_{.f}s_{if}(r_{ic}, r_{.f}) - \frac{\alpha k_i^2}{2} \tag{12}$$

The demands, $s_{ic}(.)$ and $s_{if}(.)$, follow the system (4). The maximization of the profit equation 12 with respect to r_{ic} leads to

$$\bar{r}_{ic}(k_i, k_j, r.f) = \frac{(1-\gamma)(f-c+2r_{.f})}{f+2(1-\gamma)} - \frac{f(k_i-k_j)}{3f+2(1-\gamma)}$$

Substituting the royalties $\bar{r}_{ic}(.)$ into the profit 12 leads to the profit $\bar{\pi}_i(k_i, k_j, r.f)$. At stage 2, both breeders maximize their profit with respect to k_i. This profit is concave in k_i if $\alpha > \frac{f(f+(1-\gamma))}{(1-\gamma)(3f+2(1-\gamma))^2}$ (same condition than the Base case). The resolution of stage 2 yields to the following optimal research effort

$$\hat{k}_i(r_{.f}) = \frac{(f+1-\gamma)(f-c+2r_{.f})}{\alpha(f+2(1-\gamma))(3f+2(1-\gamma)}$$

Substituting the research effort $\hat{k}_i(.)$ into the profit $\bar{\pi}_i(k_i, k_j, r.f)$ leads to the profit $\hat{\pi}_i(r_{.f})$. At stage 1, the regulator maximize the total surplus of the industry, $\hat{W} = \hat{FS} + \sum_i^2 \hat{\pi}_i$, with respect to $r_{.f}$. The resolution of the stage 1 for the interior solution yields to the optimal royalty rate

$$r^U_{.f} = \frac{\alpha(f-c)(3f+2(1-\gamma))^2(1-\gamma)+2(f+1-\gamma)(f^2+2c(f+1-\gamma)+6f(1-\gamma)+4(1-\gamma)^2)}{h}$$

With $h = 8(f+1-\gamma)^2 + f\alpha(3f+2(1-\gamma))^2$.

From this optimal value of FSS royalty, we obtain

$$\begin{aligned}
s^U_{ic} =& \frac{1}{2} - s^U_{if},\\
s^U_{if} =& \frac{cf\alpha(3f+2(1-\gamma))^2+2(f+1-\gamma)(2c(f+1-\gamma)-f^2)}{2fh},\\
r^U_{ic} =& \frac{(3f+2(1-\gamma))\cdot(1-\gamma)\cdot(4(f+1-\gamma)+\alpha(f-c)(3f+2(1-\gamma)))}{h},\\
k^U_i =& \frac{1}{\alpha h}\Big((1+f-\gamma)(4(1+f-\gamma)+\alpha(f-c)(2+3f-2\gamma))\Big),\\
\pi^U_i =& \frac{1}{2\alpha fh^2}\Big(\alpha^2 f\big(-f\big(f^2+19f(\gamma-1)-16(\gamma-1)^2\big)\\
&+3c^2(f-\gamma+1)+2c\big(2f^2+3f(\gamma-1)-4(\gamma-1)^2\big)\big)(3f-2\gamma+2)^2(f-\gamma+1)\\
&+4\alpha\big(f\big(-7f^3-14f^2(\gamma-1)+36f(\gamma-1)^2-16(\gamma-1)^3\big)\\
&+4c^2(f-\gamma+1)^2+2cf(3f-2\gamma+2)(f-g+1)\big)(f-g+1)^2\\
&-a^3f^2(\gamma-1)(c-f)(3f-2\gamma+2)^4+16f(f-\gamma+1)^4\Big),\\
W^U =& y_0 - \frac{3c}{4} - \frac{1}{4} + \frac{3c^2}{8f} - \frac{\gamma}{4} - \frac{f}{8}\\
&+ \frac{(3\alpha f^2+(2(1-\gamma)(2-\alpha c)+f(4+\alpha(2-3c-2\gamma)))^2}{8\alpha h}.
\end{aligned}$$

Moreover, for $c \leq \frac{2f^2(f+1-\gamma)}{h-4(1+f-\gamma)} \equiv \bar{c}_U$, there is a corner solution where $s^{Uc}_{if} = 0$ and $r^{Uc}_f = \frac{cf+c+f-\gamma(c+f)}{f}$. The corner solution leads to these optimal values

$$
\begin{aligned}
s_{ic}^{Uc} =&\frac{1}{2},\\
r_{ic}^{Uc} =&\frac{(c+f)(1-\gamma)}{f},\\
k_i^{Uc} =&\frac{(c+f)(f+1-\gamma)}{\alpha f(3f+2(1-\gamma))},\\
\pi_i^{Uc} =&\frac{1-\gamma}{2}\Big(1+\frac{c}{f}\Big)-\frac{(c+f)^2(f+1-\gamma)^2}{2f^2\alpha(3f+2(1-\gamma))^2},\\
W^{Uc} =&y_0-\frac{3c}{4}-\frac{1}{4}+\frac{3c^2}{8f}-\frac{\gamma}{4}-\frac{f}{8}\\
&+\frac{(c+f)\Big(\alpha+\frac{2f-c(2+3f\alpha)}{f^2}+\frac{4c}{f(2+3f-2\gamma)}-\frac{2(c+f)}{(2+3f-2\gamma)^2}\Big)}{8\alpha}.
\end{aligned}
$$

C.1.2 French system

In the French system, the regulator chooses, at the first stage, the same royalty rate on FSS for both breeders as in the UK system. The difference is during the third stage where a private organization, including both firms, maximizes the joint profit of both firms by a single royalty $r_{.c}$. The maximization of the joint profit with respect to $r_{.c}$ leads to

$$
\bar{r}_{.c}(r_{.f}) = \frac{(f-c)}{2} + r_{.f}
$$

Substituting the royalties $\bar{r}_{ic}(.)$ into the profit of each breeders leads to the profit $\bar{\pi}_i(k_i, r_{.f})$. At stage 2, both breeders maximize their profit with respect to k_i. This profit is concave in α. The resolution of stage 2 yields to the following optimal research effort

$$
\hat{k}_i(r_{.f}) = \frac{f-c+2r_{.f}}{4\alpha(1-\gamma)}
$$

Substituting the research effort $\hat{k}_i(.)$ into the profit $\bar{\pi}_i(k_i, r_{.f})$ leads to the profit $\hat{\pi}_i(r_{.f})$. At stage 1, the regulator maximize the total surplus of the industry, $\hat{W} = \hat{FS} + \sum_i^2 \hat{\pi}_i$, with respect to $r_{.f}$. The interior solution yields to

$$
r_{.f}^F = 1-\gamma-\frac{f-c}{2}
$$

From the optimal value of the FSS royalty, we obtain

$$
\begin{aligned}
s_{ic}^F =&\frac{1}{2}-\frac{f+c}{4f},\\
s_{if}^F =&\frac{f+c}{4f},\\
r_{.c}^F =&1-\gamma,\\
k_i^F =&\frac{1}{2\alpha},\\
\pi_i^F =&\frac{1-\gamma}{2}+\frac{c^2}{8f}-\frac{f}{8}-\frac{1}{8\alpha},\\
W^F =&y_0-\frac{1}{4}-\frac{\gamma}{4}+\frac{3c^2}{8f}-\frac{3c}{4}-\frac{f}{8}+\frac{1}{4\alpha}.
\end{aligned}
$$

Moreover, for $c \leq f - 2 + 2\gamma \equiv \bar{c}_F$, there is a corner solution where $r_{.f}^{Fc} = 0$ because the public authority can not set a negative royalty on FSS. The corner solution is illustrated in figure 7. The corner solution leads to these optimal values

$$
\begin{aligned}
s_{ic}^{Fc} =& \frac{1}{2} - \frac{f+c}{4f}, \\
s_{if}^{Fc} =& \frac{f+c}{4f}, \\
r_{.c}^{Fc} =& \frac{f-c}{2}, \\
k_i^{Fc} =& \frac{f-c}{4\alpha(1-\gamma)}, \\
\pi_i^{Fc} =& \frac{c^2}{8f} + \frac{f}{8} - \frac{c}{4} - \frac{(f-c)^2}{32\alpha(1-\gamma)^2}, \\
W^{Fc} =& y_0 - \frac{1}{4} - \frac{\gamma}{4} + \frac{3c^2}{8f} - \frac{3c}{4} - \frac{f}{8} - \frac{(f-c)^2}{16\alpha(1-\gamma)^2} + \frac{(f-c)}{4\alpha(1-\gamma)}.
\end{aligned}
$$

C.2 Proof of Proposition 3

The condition for obtaining a maximization of the profits with k_i is

$$\alpha > \frac{1}{9(1-\gamma)} \equiv \underline{\alpha}$$

The ranking of the welfare is as follows

1. For any parameter values, no system reaches the first best. Even if the French case leads to the optimal investment, it does not lead to the optimal ratio between CS and FSS. Even if the Australian case leads to the optimal ratio of CS and FSS, it does not lead to the optimal investment.

2. For any parameter values, we obtain $W^A > W^C > W^P > W^B$. The base case is the worst since it leads to the lowest value of investment and an inefficient ratio of CS and FSS. The Australian case dominates the Competition and Prohibition cases because it is the only one where there is the optimal ratio of CS and FSS and these three cases obtains the same level of investment ($k_i^{A,C,P} = \frac{1}{3\alpha}$).

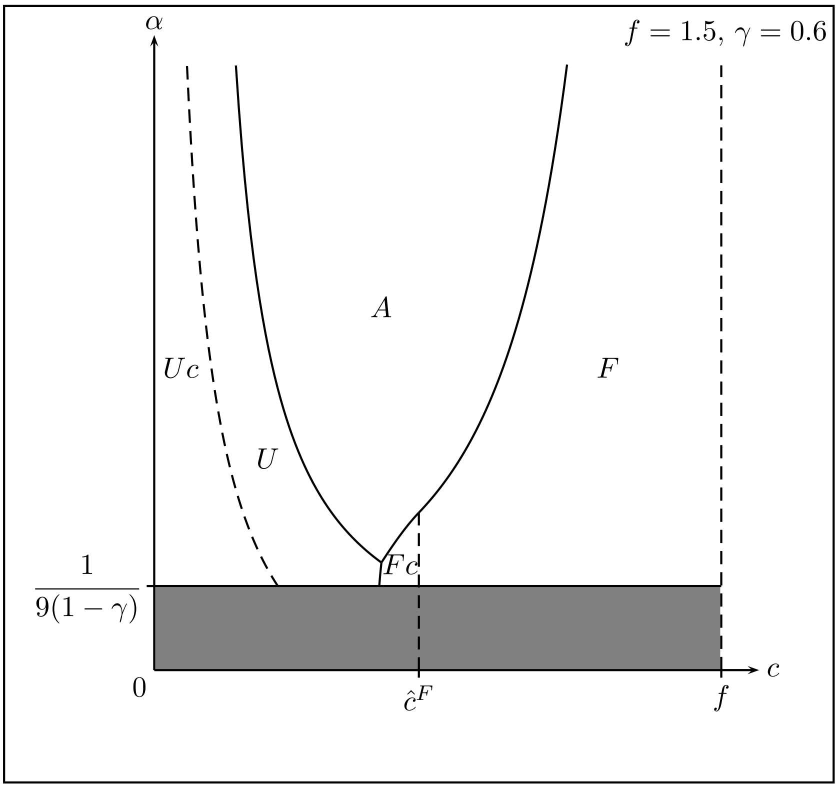
3. When the royalty on FSS in UK and French cases corresponds to an interior solution, we obtain

$$
\begin{aligned}
W^A > W^U \quad for \quad \alpha > \alpha^{AU} =& \frac{2f(f+1-\gamma)^2}{(3c(f+1-\gamma)+(1-\gamma)f)(3(cf+c+f^2)-\gamma(3c+f)+f)} \\
W^A > W^F \quad for \quad \alpha > \alpha^{AF} =& \frac{2f}{9(f-c)^2} \\
W^U > W^F \quad for \quad \alpha > \alpha^{UF} =& \frac{8c(f+1-\gamma)-2f(f+2(1-\gamma))}{(f-c)^2(3f+2(1-\gamma))}
\end{aligned}
$$

where α^{AU} decreases with c whereas α^{AF} and α^{UF} increases with c. α^{AU}, α^{AF} and α^{UF} intersect at $\bar{\alpha} = \frac{(9(1+f-\gamma)^2)}{(2f(2+3f-2\gamma)^2)}$. Therefore, the Australian cases is preferred to the UK cases for high values of α and high values of c and the Australian cases is preferred to the french cases for high values of α and low values of c. Below $\bar{\alpha}$, since α^{UF} is increasing with c, the UK case gives a higher welfare for low values of c compared to the french case.

4. When the royalty on FSS in UK case corresponds to the corner solution ($c < \bar{c}_U$), we always obtain for $c < \bar{c}_U$ and $\alpha > \frac{1}{9(1-\gamma)}$ that $W^{Uc} > W^F$ and $W^{Uc} > W^A$.

Figure 7: Second best with innovation and a covered market



D Noncovered market with investment in R&D

The equilibrium with a noncovered market and endogenous investment in R&D gives rather complex expression that we do not detail here. We focus here on the comparison of total welfare with the different royalty systems. We first present partial comparison between some of the royalty system that enables to eliminate those are dominated in terms of total welfare and compare, at last, those that can be dominant depending on the values of the parameters. The first and the third results can be established analytically while the two other ones are established on the basis of simulations.

- Comparison of A, C and P. These three systems lead to the same total quantity and the same research investments at the equilibrium. The Australian system fully dominates the Competition and the Prohibition systems because it leads to lower seeds production cost (cf. seed production efficiency effect, lemma 1).

- Comparison of A and B. The Australian system does necessarily dominates the Base system for all parameters values, as in the case with a covered market. Indeed, for high research cost (α), the investment effort does not provide a sufficient quality improvement for the society compared to an increase of the total quantity of seeds. In the Australian system firms do not internalize how the total quantity affect positively the welfare. Therefore, the royalty on FSS and CS stays high leading to a negative impact on the total quantity compared to the Base case where there is no royalty on FSS. Thus, if it is very costly to innovate, the Base system is preferable compared to the Australian system.

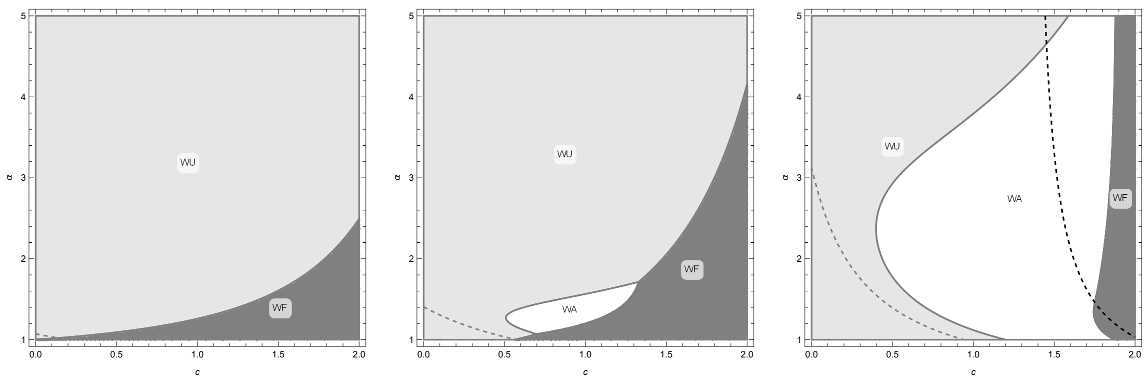
- Comparison of U and B. The UK system fully dominates the Base system. One simple explanation is that the Base system is a particular case of the UK system where the regulator define a free royalty on the FSS. Thus, if the regulator defines a positive royalty to maximize the total welfare in the UK system, then it necessarily leads to higher welfare compared to the Base system. In more detail, we can observe that, compared to the Australian system mentioned above, the regulator internalize all effects on the welfare in the UK system. For a rise of the research costs, the regulator lowers the royalty on FSS that indirectly decreases the royalty on CS. Therefore, compared to the Australian system, the research investment is lowered and total quantity is increased.

Synthesizing the last two results, we can conclude that even if the Base system dominates the Australian system, it is dominated by the UK system. Conversely if the Australian system dominated the Base system, it can also dominates the UK system.

- Comparison of F, A and U. As in the previous sections, the three systems that dominate all the others in terms of welfare are the UK, the Australian and the French systems. The Figure 8 shows the best out of these three systems for different parameters values. There are corner solutions for the UK and the French systems for the same reasons than those explained with a covered market (see section 3.3). The corner solution for the UK system is at the left of the gray dashed line, and the corner solution for the french system is at the left of the black dashed line. Note that c can now be higher than f since the total quantity is no longer restricted to unity.

Figure 8: Second best with innovation and a non covered market ($y_0 = 4$ and $f = 1.5$)

(a) $\gamma = 0.25$ (b) $\gamma = 0.5$ (c) $\gamma = 0.75$



In this version of model, the total demand of seeds can increase thanks to a lower price and/or a higher quality of the product (increasing the farmers' willingness to pay). In the aim of increasing the quality, the regulator sets a higher royalty rate on FSS that indirectly increases the royalty rate on CS. This policy gives the proper incentives to innovate to breeders. However, it has a countervailing effects in terms of welfare in a non-covered market, because the higher royalties decrease the demand of seeds from farmers. As a consequence the policy in terms of royalty rates on FSS will differ depending on the efficiency of investments (α), especially in the UK systems. For a low value of the research cost parameter (α), the royalty on FSS will be set by the regulator at an higher level than the royalty rate on CS. Conversely, for a very high value of the research cost the royalty on FSS will be lower than the royalty on CS. The royalty rate on FSS is also decreasing for high values of research cost in the French system. However, the choice of the regulator in terms of royalty on FSS affects to a lesser extent the royalty rate on CS sets by a cartel. Therefore, the UK system leads to a higher welfare than the Australian system even for high values of the research cost parameter. Indeed, both royalties are lowered compared to the Australian system, increasing the total quantity of seeds in the market.

The subtitutability parameter (γ) affects in a greater extent the results in a non-covered market. Indeed, if seed varieties are weakly substitutable (low value of γ), firms can increase their mark-up through an increasing level of royalty that will affects negatively the total demand and the welfare. This effects is lowered in the UK and the French system thanks to the royalty on FSS chosen by the regulator. Therefore, for low values of the substitutability parameter, the Australian system is dominated either by the UK case or the French case.