Patents v. Open Source: What is the socially optimal way to secure IP payments when the innovation's success is uncertain?

by

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Abstract: Consider the owner (*Ph*) of a basic innovation that cannot be commercialized without further developments. The latter are risky and must be undertaken by independent risk-averse developers (*D*s). The traditional Patent Protection (*PP*) grants the innovation owner exclusion rights, allowing him to grant the right to use the innovation only to the *D*s who agree to pay ex-ante a fixed amount in order to secure the right to use the innovation, and a predetermined royalty per unit sold, in case their development ends up being successful. With the recently proposed open-source (OS), all the *D*s are allowed free access to the innovation, provided that they pay royalties in case of successful development. We assume *D*s to be distributed according to their risk aversion parameter and show that when the width of their distribution is relatively narrow, the expected number of new products is higher under *OS* compared to *PP*. Despite this, consumers may be happier with *PP*, since the per-market surplus is sufficiently higher as to compensate for the smaller number of products. When the width of the distribution is sufficiently large, in case of *PP* the *Ph* offers the innovation at a negative fee (subsidy) in order to attract larger part of the mass of *D*s. In such a case, *PP* yields a larger number of expected new products. Paradoxically, it is in this region that consumers may prefer the *OS*, since it produces higher surplus per market.

1. Introduction

Modern economics consider intellectual property (IP) and its protection as a *sine qua non* for innovation. The traditional means for protecting IP is patents, which offer to their owner monopoly rights for a limited time period. These rights are supposed to generate the necessary rents for recovering past research costs and providing incentives for new research in the future. Usually, IP is protected through a patent protection system (*PP*) that grants the patent holder (*Ph*) the right to limit the use of his innovation to those he wishes (exclusion right).

In many instances the basic invention cannot be directly consumed, requiring instead additional R&D before yielding a final product that can respond to consumer desires. Very often this additional R&D must be carried by developers (*D*) that are different than the patent holder. An example central to our motivation, is that of patented plants obtained through genetic editing. Usually, these plants require that their traits be assembled with other traits before yielding marketable products; this part of the final product's development must be carried out by special breeders, outside the firm that has invented the genetically modified basic plant. Each breeder usually develops a unique differentiated product and has exclusive rights upon its commercial exploitation.

Other example is that of an upstream firm that spends money in creating a brand name but decides to let other firms sell specific products carrying that brand name to consumers. A typical example is franchising, where an upstream firm creates the brand name and sets the products' norms, while different downstream firms must bear the cost of commercializing the product to consumers. While in this case the upstream firm may also require that the franchisees purchase some intermediate inputs from it, in some cases it may only require a royalty in terms of an input price.

Crucial in all the above examples is the presence of risk in the development of a final product. Indeed, in many cases the final product meets no commercial success, leading to a loss of the investments, whether physical or in terms of effort, used in its development.

Why a *Ph* might want to reduce the number of *D*s? If the *D*s are all similar and operate in completely independent markets, there is no reason for the *Ph* to limit their number. If they are similar but sell not fully differentiated products, then of course the *Ph* must select the optimal number of downstream varieties. If the final products are completely independent but the *D*s differ among them, or sell at markets of differing size the *Ph* must again restrict the number of developers, unless he is able to exercise 1st degree price discrimination in selling the rights to use the innovation.

In this work we focus on a single *Ph* facing a multitude of *D*s who develop completely independent products, so if successful, each of them becomes a monopolist. We assume that the demand characteristics of all the potentially developed varieties are similar, and the success probability is the same for each product. *D*s however are risk-averse and they differ among them with respect of their degree of risk-aversion. Thus, if all are offered contracts with similar terms, some may decline the offer because the expected return—common to all—may not be sufficient to compensate for their risk-aversion. We assume that the *Ph* cannot distinguish among *D*-types, so he is not able to propose a specific contract to every developer.

The traditional patent protection system (*PP*) allows the Ph to gain revenue from both, selling the right to use his patented innovation and receiving a share from the generated profit. We interpret *PP* as a *two-part* tariff (*TP*) where the right to use the innovation corresponds to a fixed payment.

The *PP* system has recently become subject of serious criticism for overly restricting the use of the basic invention to only a limited number of *D*s, thus leading to the development of too few new products (see Van Overwalle, 2018). As an alternative, a number of legal scholars propose that IP be protected by a system of Open Source (OS) which secures payments to the Ph only through royalties and without the exclusion rights provided by the patent system. The way the OS system works is simple: every developer is free to use the basic innovation provided that she pays back to the *Ph* a predetermined portion of her receipts from selling her product (royalty). Important institutions such as the INRA-E in France openly support the replacement of a patent system by an OS one.

The central question of our research is: ***does the OS system provide indeed wider access to, and more use of the basic invention compared to the existing patent system?*** The question may seem trivial since in the case of *OS* part of the payment takes place ex-post, but one must take into account that the royalty is also different in the two systems. Moreover, it has been shown that a two-part tariff provides better insurance to a risk-averse downstream seller.

As it turns out, in equilibrium the *OS* indeed attracts a higher number of developers, but this advantage is reduced as the R&D cost rises and/or the *D*s become more similar in their risk aversion. For every width of the distribution of developers, there is a level of R&D cost at which the two systems result in equal market coverage. Past that level, the *Ph* may not demand a positive price for the right to use the innovation. The *TP* scheme, and therefore exclusion, may work only if the *Ph* is able to finance specific products, through joint-venture, otherwise the *PP* collapses to *OS*.

Besides comparing *OS* to the *PP* in terms of number of products, we also compare their performance in terms of consumer surplus and total welfare. We identify two effects that are crucial for both these welfare measures and work in opposite directions. First, the surplus *per-market* (intensive margin), which is higher, the lower the value of the royalty is. When the R&D cost is low, the presence of a positive fixed cost in the *PP* system allows for lower royalty and higher surplus per market, a standard result in vertical relations. This result can be completely reversed if the cost of R&D is so high as to require a negative fixed payment as part of the *TP* tariff scheme. Second, the *number of markets* (extensive margin) which is higher, the lower the fixed payment is (higher royalty). Thus, when the R&D cost is relatively low as to allow the *Ph* to require a high fixed payment for the use of his innovation, the number of products is severely restricted and welfare is reduced. Besides the R&D cost, both effects depend on the heterogeneity of *D*s with respect to their risk-aversion.

The overall relative evaluation of PS and OS is ambiguous. Taking the development cost and the width of Ds' risk-aversion distribution as main exogenous parameters, we identify parameter regions where one or the other system produces higher consumer surplus and overall welfare. The PS is superior for high and for low levels of *F* while the superiority of the OS is concentrated at middle levels of the fixed cost.

Reisinger and Schnitzer (2012) and Milliou and Petrakis (2020) show that linear tariffs can be welfare-superior to two-part tariffs by inducing more entry in the downstream market. However, these studies do not consider demand uncertainty and/or fixed costs and thus the driving mechanism is different.[1]

When dealing with a downstream firm, an upstream supplier can achieve vertical coordination by using a two-part tariff: the (per-unit) input price is set equal to marginal cost, and downstream profits are appropriated through the fixed fee. This coordination may be prevented under demand uncertainty: given downstream risk-aversion, the supplier engages in risk-sharing and charges a per-unit input price above marginal cost (Rey and Tirole, 1986). Lømo (2020) considered the case where an upstream supplier offers secret two-part tariff contracts to several downstream firms that face demand uncertainty. His focus was on the well-known commitment problem (e.g., Hart and Tirole, 1990; O'Brien and Shaffer, 1992; McAfee and Schwartz, 1994; Rey and Tirole, 2007): the supplier undercuts its own input prices and fails to offset retail competition. He shows that this problem diminishes when retailers are risk averse and face demand uncertainty. In Lømo (2020), there are no downstream fixed costs, the number of downstream firms is exogenously given, and the case of linear tariffs is not considered. Moreover, in our paper there is no commitment problem as downstream firms operate in different markets.

Closely related to the present paper is that of Constantatos and Pinopoulos (2023) in the sense that they also consider demand uncertainty, downstream fixed costs and linear vs. two-part tariffs. However, in their setting, there is only one downstream firm, and thus they do not investigate the effects of linear vs. two-part tariffs on the number of downstream firms (markets).

2. The Model

Description of the *Downstream market*

The probability of success is ½. In case of failure, the quantity demanded is zero at any price. If successful, developer *i* sells a product that is completely independent from that of other developers, she is therefore a monopolist facing a linear demand of the form $q_i = 1 - p_i$.

There is a fixed cost *F* necessary to implement downstream operations, which is irrecoverable in case of an unlucky outcome. No variable production cost is considered. Under the PP scheme, every *D* must pay an additional fixed cost *T* (over and above *F*) which represents a transfer to the Ph, in exchange for the right to use Ph's basic innovation. This payment is determined endogenously by the Ph and can be negative in some cases.

[1] Kourandi and Pinopoulos (2023) also show that linear tariffs can be welfare-superior to two-part tariffs in a setting where an independent downstream firm competes in prices and bargains with a vertically integrated supplier.

Description of *Ds' utility*

Developers are risk averse, characterized by varying degrees of risk aversion. A typical developer's utility function takes the well-known "mean-variance" form:

$$U_i = \hat{\pi} - T - \varphi_i \sigma^2(w) - F$$

where:

- $w \geq 0$ is a royalty payment
- $T \gtreqless 0$ is the transfer payment that may be required by the Ph, which can be positive or negative (when negative transfer payments are allowed)
- $\hat{\pi} = p(\hat{q}(w)) \cdot \hat{q}(w)$ is the expected net profit from a successful R&D, gross of any transfer payments to the Ph
- $\varphi_i \geq 0$ is the risk-aversion coefficient of developer *i*.
- $\sigma^2(w)$ is the maximized-profit variance between the states of success and failure

Developers are distributed according to the degree of their risk aversion. In order to rule out the presence of "nearly risk-neutral" agents, we assume that $\varphi_i = \underline{\lambda} + \lambda_i$, where the parameter $\underline{\lambda} > 0$ is a shift parameter expressing an initial level or risk-aversion applying to all agents.

A common concern with the mean-variance utility function is that it may not respect 1st degree risk dominance. This, in our case would imply the presence of agents that are so risk-averse that their utility increases with *ceteris paribus* reductions in their good-state payments. To avoid such behavior, we assume that no *D* is so risk-averse as to prefer *ceteris paribus* a higher royalty payment *w, i.e.,* we impose that in all outcomes:

$$\frac{\partial U_i}{\partial w} < 0 \qquad (dPer)$$

We call this the *dPer* condition.[2] The *dPer* condition guarantees the satisfaction of 1st degree risk-dominance by imposing an upper bound $\overline{\lambda}$ on the admissible values of *λ*, hence $\lambda_i \in [\underline{\lambda}, \overline{\lambda}]$.

Description of the *Upstream market*

We assume that the basic invention has been already obtained and there is no variable of fixed cost in making it available to Ds. The Ph offers a take-it-or-leave-it contract to all Ds. In case of *PP* the contract contains a fixed payment *T* in order for the developer to secure the right to do R&D, and a royalty w_2 out of the final product's sales. If an OS system is adopted every *D* is free to try to develop her product, being required to pay only royalties ex-post. Hence, we interpret *OS* as a linear contract (*L*) which instead of an input price contains a variable payment

[2] Thanks to prof. Perrakis for pointing this out to us.

w_1 per unit of final product sold in the form of royalty. The equivalent interpretation of *PP* is a two-part tariff (*TP*) containing a fixed payment *T* and a royalty w_2. In all cases, royalties are paid ex-post and only in case of successful product development. The *TP* related transfer *T* is paid before the resolution of uncertainty and is not recoverable in case of failure. Hereafter, we use the subscripts 1,2, to refer to the *L* and *TPT* cases, respectively.

The *Ph* is assumed to be risk neutral, although we may show numerically that most of our results hold even if the *Ph* is also risk-averse. *Ph*'s risk neutrality can be justified by the multiplicity of developers who represent a multiplicity of independent projects.

3. Analysis

We assume that the choice between *OS* and *PP* has been determined institutionally from the outset and consider two three-stage games, game 1 and 2, respectively. At the first stage of either game the *Ph* sets the contract terms and at the second each *D* decides whether to accept, in which case she invests a fixed cost *F*. Then, Nature decides success or failure for each project with exogenously given probabilities $z, (1 - z)$, respectively; assume for simplicity that $z = 1/2$. Each developer who observes a successful outcome markets her product, while unsuccessful ones lose any fixed payments they made up to that point.

Third stage

Let a "*" indicate optimized values and a "hat" indicate expected values. Let also (q, π) indicate quantity and gross profit (fixed cost included) in the final-product market. Then, it is straightforward to show that

$$\hat{q}^*(w) = \frac{1 - w}{4}, \tag{1}$$

$$\hat{\pi}^*(w, F) = \frac{1}{8}[-8F + (1 - w)^2] \tag{2}$$

In order to avoid trivial cases, we assume that $\hat{\pi}^*(w, F) > 0$, *i.e.*, $F < \bar{\bar{F}} = 1/8$.

Second stage

In the 2nd stage each *D* accepts the contract proposed by the *Ph* if, in case of *L*:

$$U_i = \hat{\pi}^*(w_1) - (\underline{\lambda} + \lambda_i)\sigma^2(w_1) - F \geq 0 \tag{3.1}$$

and in case of *TP*:

$$U_i = \hat{\pi}^*(w_2) - T - (\underline{\lambda} + \lambda_i)\sigma^2(w_2) - F \geq 0 \tag{3.2}$$

Let λ_1, λ_2, be the values of λ that set $U_i = 0$ in (3.1), (3.2), respectively. Since the RHS of both expressions is decreasing in λ, all *D*s with $\lambda_i > \lambda_k, k = 1,2$, reject the *L* or the *TP* contract, according to the case.

First stage

We assume that the Ph faces a mass of *D*s distributed according to their risk-aversion coefficient. The Ph knows the distribution of Ds, but cannot sort individual types. For each contract type, the *Ph* maximizes revenue by choosing w_1, or (w_2, T), according to the case, subject to the constraint that (3.1) or (3.2) be satisfied for the marginal developer.

Open Source (*L*)

Since the *L* contract provides only one instrument for both maximizing profit and satisfying the constraint, its optimal form accepts several corner solutions, to which we come back later.

Assuming an ***interior solution***, the Ph's problem is described as:

$$\max_{w} \Pi_1 = G(\lambda_1(w); \underline{\lambda}, \Lambda, F) * w\hat{q}(w)$$

$$\text{s. to} \quad U(\lambda(w)) \geq 0$$

Setting the constraint equal to zero we obtain that

$$\lambda_1^0 = \lambda_1^0(w; \underline{\lambda}, \Lambda, F)$$

which substituted back to the objective function yields

$$\Pi^0(w) = \max_{w} \Pi_1 = \Pi_1(w; \underline{\lambda}, \Lambda, F)$$

Patent Protection (*TP*)

The Ph's program is

$$\max_{\{w,T\}} \Pi_2 = G(\lambda_2(w, T), ; a, \Lambda, F) * [w\hat{q}(w) + T]$$

$$\text{s.to } U(\lambda_2) \geq 0,$$

where *G* is the cumulative distribution of all Ds that accept the contract.

From (3.2) we can replace *T* by

$$T = \hat{\pi}^*(w) - F - (\underline{\lambda} + \lambda)\sigma^2$$

and use λ instead of T as choice variable, so the maximization problem of the Ph becomes:

$$\max_{\{w,\lambda\}} \Pi_2 = G(\lambda; a, \Lambda, F) * [p\hat{q}(w) - F - (\underline{\lambda} + \lambda)\sigma^2]$$

The FOC are:

$$G_\lambda * \left[p\hat{q}(w) - F - \left(\underline{\lambda} + \lambda\right)\sigma^2\right] - G\sigma^2 = 0$$

$$G(\lambda; a, \Lambda, F) - p'\hat{q}(w) - p\hat{q}'(w) - \lambda\frac{\partial\sigma^2}{\partial w} = 0$$

About the distribution of *D*s

Deriving again the first of the FOCs in the *PP* problem with respect to λ we obtain

$$G_{\lambda\lambda}\left[p\hat{q}(w) - F - \left(\underline{\lambda} + \lambda\right)\sigma^2\right] - 2G_\lambda\sigma^2 < 0$$

Since the term in square brackets is positive, a sufficient condition for the second order conditions to hold is the distribution of *D*s according to their risk-aversion to exhibit decreasing density, otherwise the *TP* problem admits only a corner solution where the patent protected *Ph* serves the entire market. To make things tractable, we assume that the developers' risk aversion follows a monotonically decreasing triangular distribution with probability density $g(\lambda) > (=)0$, $\forall\lambda \in (\notin)[\underline{\lambda}, \underline{\lambda} + \Lambda)$ and mode at $\underline{\lambda}$.[3] Thus, the probability density function is:

$$g(\lambda) = \frac{2(\Lambda - \lambda)}{\Lambda^2}, \qquad \underline{\lambda} \leq \lambda < \underline{\lambda} + \Lambda$$

with

$$g'(\lambda) = -\frac{\lambda}{\Lambda^2} < 0$$

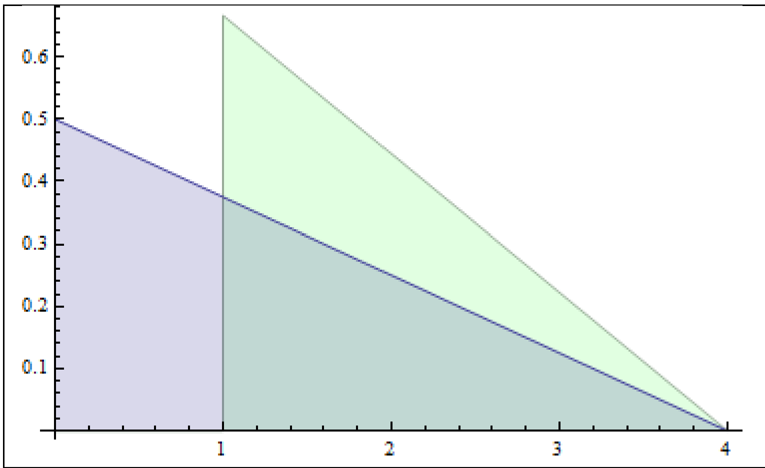
and cumulative density function:

$$G(\lambda) = \frac{\lambda(2\Lambda - \lambda)}{\Lambda^2}$$

The presence of $\underline{\lambda}$ allows us to bound from below the risk-aversion coefficient, away from 0. This is particularly important since the mode is at the beginning of the distribution. Letting $\underline{\lambda} = 0$ could be a good starting point for it gives the simplest solutions, but would imply that a good portion of *D*s are close to risk-neutrality, a rather unrealistic assumption. Since the highest value of the risk-aversion coefficient is bounded by the *dPEr* assumption, the width of the distribution must be adjusted as to not exceed that value, which in our case (due to the assumed demand and probability of success) is $\overline{\lambda} = 4$. Thus, $\Lambda \leq 4 - \underline{\lambda}$; in all figures and numerical applications we assume that $\Lambda = 4 - \underline{\lambda}$. The following figure shows two such distributions, with initial point and mode at 0 and 1, respectively.

Figure 1.

[3] The usual assumption of uniform distribution breaks the second order conditions or the *TP* problem leading to a corner solution where the *Ph* serves the entire market.



Figure

- The Blue distribution is traced for $\underline{\lambda} = 0, \Lambda = 4$
- The Green distribution is traced for $\underline{\lambda} = 1, \Lambda = 3$

- Proof of the characteristics of the distribution.
  - We know that

$$\frac{1}{2}\Lambda g(\underline{\lambda}) = 1 \Leftrightarrow g(\underline{\lambda}) = \frac{2}{\Lambda}$$

hence

$$g' = -\frac{g(\underline{\lambda})}{\Lambda} = -\frac{2}{\Lambda^2}$$

therefore

$$g(\lambda) = -(\underline{\lambda} + \Lambda - \underline{\lambda} - \lambda)g'(\lambda) = (\Lambda - \lambda)\frac{2}{\Lambda^2}$$

and

$$G(\lambda) = 1 - \frac{1}{2}(\Lambda - \lambda)g(\lambda) = 1 - \frac{1}{2}(\Lambda - \lambda)(\Lambda - \lambda)\frac{2}{\Lambda^2} =$$

$$1 - \frac{(\Lambda - \lambda)^2}{\Lambda^2} = \frac{\Lambda^2 - \Lambda^2 + 2\lambda\Lambda - \lambda^2}{\Lambda^2} \Leftrightarrow$$

$$G(\lambda) = \frac{\lambda(2\Lambda - \lambda)}{\Lambda^2}$$

Distributions with $\underline{\lambda} > 0$ imply that no *D* exists with risk-aversion coefficient between 0 and $\underline{\lambda}$. However, our results are not substantially affected if we introduce a small mass of consumers with uniform or even upward sloping density distribution in that interval. Due to the linear or convex cumulative function in the $(0, \underline{\lambda})$ the *Ph* will cater all the *D*s on that interval independently of how many he decides to cater on the other side of $\underline{\lambda}$. Since the same contract must be offered on both sides of $\underline{\lambda}$, an amelioration of contract terms in order to reach more *D*s on the RHS of $\underline{\lambda}$ would imply a profit reduction by all the inframarginal Ds. All the identified forces are at work except that for a sufficiently large mass of consumers in the $(0, \underline{\lambda})$ we may have a corner solution at $\lambda = \underline{\lambda}$, i.e, the *Ph* may decide to cater none of the *D*s with risk-aversion coefficient higher than $\underline{\lambda}$. If the cumulative density in the $(0, \underline{\lambda})$ is sufficiently small, the presence of consumers in that interval has only quantitative effects on the monopolist's optimal solution.

Using our assumptions of linear demand, probability of success equal to ½, and triangular probability distribution of risk-aversion, we obtain:

Open source (linear tariff)

Since the *L* contract provides only one instrument for both maximizing profit and satisfying the constraint, its optimal form accepts several corner solutions, to which we come back later. Assuming an ***interior solution***, we set the constraint equal to 0, to obtain

$$\lambda_1^0 = \lambda_1^0\left(w; \underline{\lambda}, \Lambda, F\right) =$$

$$\frac{(-64F+8(1-w)^2-(1-w)^4\underline{\lambda})(64F+(1-w)^2(-8+(1-w)^2\underline{\lambda}+2(1-w)^2\Lambda))}{(1-w)^8\Lambda^2}$$

which substituted back to the objective function yields

$$\max_{w} \Pi_1 = \Pi_1\left(w; \underline{\lambda}, \Lambda, F\right)$$

Maximizing with respect to *w*, we obtain as first order condition which is a high order polynomial expression with multiple roots.

Patent Protection (two-part tariff)

$$\max_{\{w,\lambda\}} \Pi_2 = \frac{1}{64\Lambda^2}\left\{\lambda\left[8(-8F + (1-w_2)^2) - 16(-1+w_2)w_2 - (1-w_2)^4(\underline{\lambda}+\lambda)\right](2\Lambda - \lambda)\right\}$$

The first order conditions (FOCs) are

$$\frac{\partial \Pi_2}{\partial \lambda} = \frac{1}{64\Lambda^2}\left\{\lambda\left[-16w + 4(1-w)^3(\underline{\lambda}+\lambda)\right](2\Lambda - \lambda)\right\} = 0$$

$$\frac{\partial \Pi_2}{\partial w} = \frac{1}{64\Lambda^2}\left\{\lambda\left[16(-1+8F+w^2) + 2(-1+w)^4\underline{\lambda} + 3(-1+w)^4\lambda\right] - 2\Lambda\left[64F + (-1+w)(8+8w-\underline{\lambda}+3w_2\underline{\lambda} - 3{w_2}^2\underline{\lambda} + w^3\underline{\lambda} + 2(-1+w)^3\lambda)\right]\right\} = 0$$

Solving the first FOC yields

$$\tilde{\lambda}_2 = \frac{4w - \underline{\lambda}(-3w + 3w^2 - w^3)}{(1-w)^3}$$

which substituted into the other FOC yields a high order polynomial with multiple roots. With the help of *Mathematica* and checking numerically for the 2nd order conditions we identify the proper root, which is extremely complex and can serve no analytical purpose; it can nevertheless be the basis for numerical analysis. Numerical analysis also shows that the so calculated value of λ_2 is never above Λ, hence there is no issue of corner solutions.

The analysis must hereafter proceed numerically. Let λ_1 and the pair (w_2, λ_2) denote the profit-maximizing terms of the L and TP contract, respectively.

4. Comparisons

In order to examine the number of expected products that will be developed under each IP protection system let $l_i = \frac{\lambda_i}{\Lambda}, i = 1,2,$ indicate the extent of market coverage in the developers-market, under an *OS* or *PP* system of IP protection, respectively. The following proposition states that the system that results in higher royalty is the one that attracts more developers. The proof of the following three lemmas is numerical and presented in Figure 2.

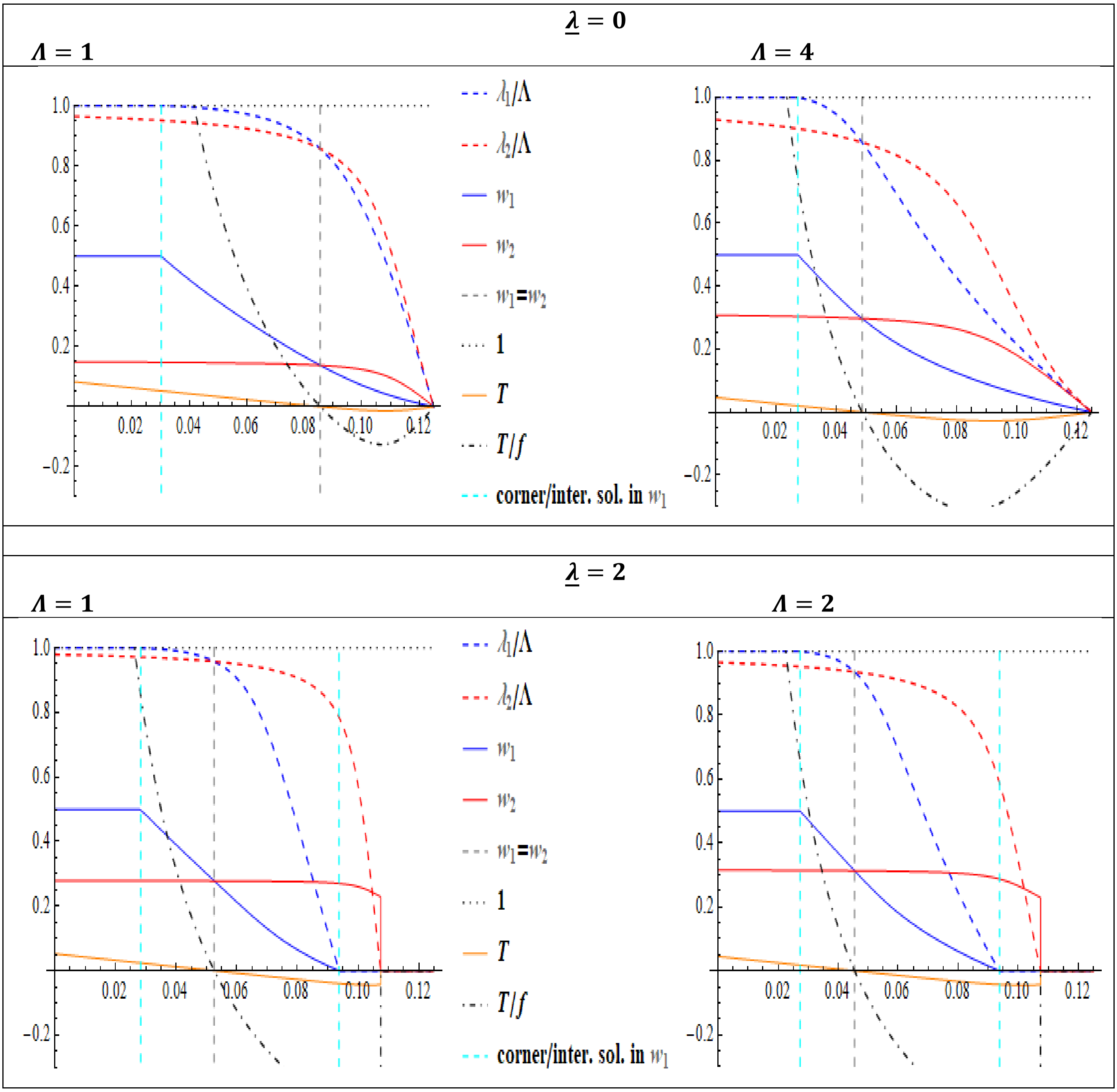
Lemma 1: *In presence of uncertainty and absent corner solutions, the royalty contained in the optimal TP tariff (PP system) is positive and independent of the fixed cost. The corresponding market coverage* l_1 *is always less than 1 and decreasing in F.*

Lemma 2: *For low values of F, the optimal royalty under a L tariff is* $w_1 = 1/2$ *, and market coverage is full (corner solution with* $\lambda_1 = \underline{\lambda} + \Lambda$*). For higher levels of F, the profit-maximizing royalty* w_1 *is decreasing in F and so is the extent of market coverage.*

Proof: The proof is numerical and is illustrated on the following figures.

Lemmata 1-3 are illustrated on figure 2. The two upper panels are drawn for $\underline{\lambda} = 0$, while the lower ones, for $\underline{\lambda} = 0$. In all the panels, the horizontal axis shows fixed cost levels (*F*) and the vertical axis indicates both the optimal royalty (w_i) and relative coverage (l_i) under each IP system. More specifically, solid lines indicate w_i and dashed lines, l_i. Blue color is associated to *OS* while red to *PP*. The orange line stands for *T* (the fixed transfer with *TP* tariff) whereas the black dashed-and-dotted line shows the ratio *T/F*. Both lines cross the horizontal axis when the optimal royalty is the same under the two schemes.

Figure 2.



Proposition 1: *Let* $\underline{\lambda} \in [0,4)$, $\Lambda \in (0, 4 - \underline{\lambda})$ *and* $F \in (0, \overline{F})$.

- *i) For any given* $\underline{\lambda}$ *there is a locus of points on the* (Λ, F) *space, call it H, along which* $w_1(F, \Lambda; \underline{\lambda}) = w_2(F, \Lambda; \underline{\lambda})$*;*
- *ii) The H locus is monotonically decreasing and convex, dividing the space of admissible* $(F.\Lambda)$ *values in two regions: region I and II, such that in region I (II):*

- $w_1 > (<) w_2$
- $T > (<) 0$.

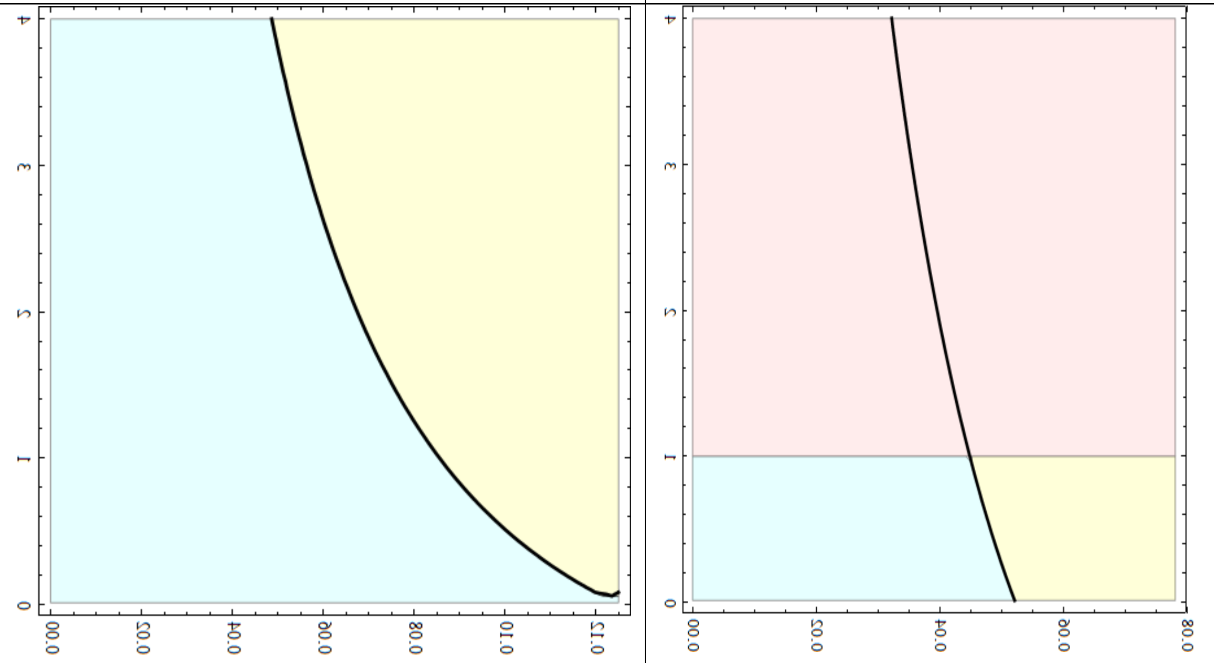
▪ *iii) While for every admissible value of Λ there exists a value $F_H(\Lambda)$ such that the pair $(\Lambda, F_H(\Lambda)) \in H$, the reverse is true only when $\underline{\lambda} = 0$;*

▪ *iv) the H locus is displaced upwardly with increases in $\underline{\lambda}$.*

The proposition is illustrated on the following figure (figure 3) where the horizontal axis depicts *F* and the vertical axis *Λ*; the two panels are drawn for different values of $\underline{\lambda}$. The pink areas correspond to areas that must be excluded for not respecting the *dPer* condition (1st order stochastic dominance). The horizontal axis is limited to values of *F* that allow the market to exist under both schemes.

Figure 3.

$\underline{\lambda} = 0$	$\underline{\lambda} = 3$



The cyan area depicts region I where $T > 0$ and the classical relation $w_1 > w_2$ holds. In the light-yellow area (region II), $T > 0$ and $w_1 < w_2$. Thus, for any spread of the distribution, when the fixed cost is high the *Ph* may find it profitable to subsidize research on his innovation, basing his earnings on high royalties. Such subsidization possibility does not exist in the *OS* system. Note also that for some values of *F* above those shown, the market only survives under a *TP* tariff with negative transfer (research subsidization).

The following proposition examines the relative market coverage, and thus the number of expected new products, under the two schemes.

Proposition 2: *When the cost F of R&D is sufficiently low relative to the spread of the distribution of developers as to yield positive price for the right to use the innovation, then the OS results to more products compared to PP. For high levels of F, when research subsidization is feasible, the exclusion rights that the PP offers to the Ph help maintain a larger number of products, compared to OS.*

Proof: The proposition can be illustrated numerically on Figure 2, above (not repeated here). Recall that in all the panels, the blue (red) dashed line shows market coverage in case of *OS* (*PP*). The two lines cross exactly at the level of *F* where the royalty is the same in both systems and the profit-maximizing price of the right to use the innovation is zero.

Relating proposition 2 to proposition 1, when the terms of the profit-maximizing *TP* contain a positive fixed transfer, the *OS* system offers more new products. This can be reversed if the *TP* implied by a *PP* system is negative. Alternatively, it can be said that coverage is higher in the market where the ex-post payment is larger, as suggested by intuition. For high levels of *F*, the *PP* yields a higher number of products only under the condition that the *Ph* is able to engage in joint venture, financing part of *D*s' fixed cost. If that condition is not met, no TPT pricing is possible for values of *F* to the right of the intersection point between the two solid lines, thus the region where the *PP* produces more products disappears.

Turning to consumer surplus and total welfare we note that the system that offers higher royalty reaches more *D*s (advantage at the extensive margin) but at the same time suffers from higher double-marginalization inefficiency (per-market disadvantage). Thus, no *a priori* judgment can be made. Note, however, that when *F* is small, market coverage under any system is relatively high, therefore a small increase at the extensive margin is not very highly valued. At the same time, the double-marginalization inefficiency is relatively important due to the fact that both the *PP* and *OS* contain a royalty above marginal cost. Hence, at low levels of *F* we expect the *PP* to be more efficient than the *OS*.

At very high levels of *F* the relative merits of improving at the extensive and intensive margins are reversed: an increase in the number of products is now relatively more important than an efficiency increase in each market. However, ***equally reversed is the relative advantage of each system***, since it is now the *PP* that offers more products, but the *OS* provides higher surplus per market.[4] While it may appear that the *PP* is always welfare superior, we find intermediate levels of *F* for which the *OS* produces higher welfare.

[4] The possibility of a linear tariff to produce higher surplus compared to a two-part tariff with negative fixed fee has been explored in Constantatos and Pinopoulos (2023) for the case of a single risk-averse firm in the downstream market.

- **Proposition 3:** *i) For high and low levels of the fixed cost, the PP produces higher consumer surplus even in situations (low F) where the OS produces a higher potential number of products; ii) there is an intermediate range of F values where the OS produces higher consumer surplus; the superiority of OS occurs for values of* (F, Λ) *for which the profit maximizing value of T = 0.*

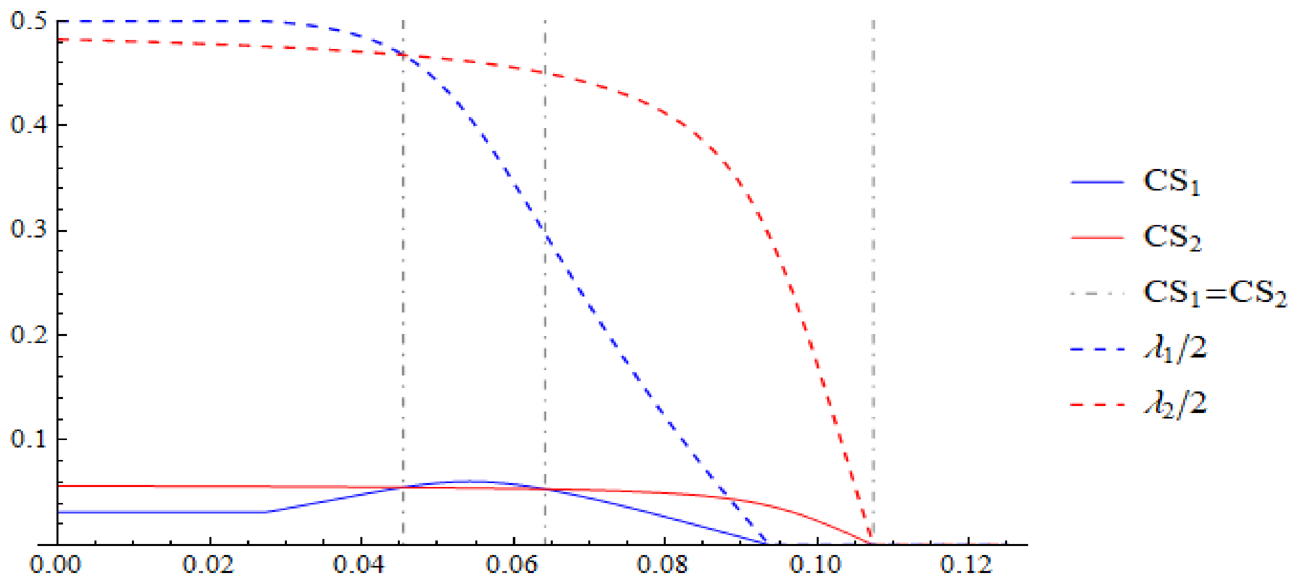
  - **Proof:** The proof is again numerical and illustrated in the following figures: **Figure 4** illustrates the evolution of consumer surplus for a given width of the distribution (Λ), while **Figure 5** identifies all the (F, Λ) combinations for which each system provides higher consumer surplus.

Figure 4.

The figure is drawn for ($\underline{\lambda} = 2,\ \Lambda = 2$**);** blue (red) lines stand for *OS* (*PP*); solid lines show consumer surplus under each regime, whereas the dashed lines show percentage of market coverage. The percentage of market coverage has been divided by 2 (hence, at $\lambda_i =$ 0.5 there is full market coverage) in order to limit the impact of the dashed lines on the figure's scale.

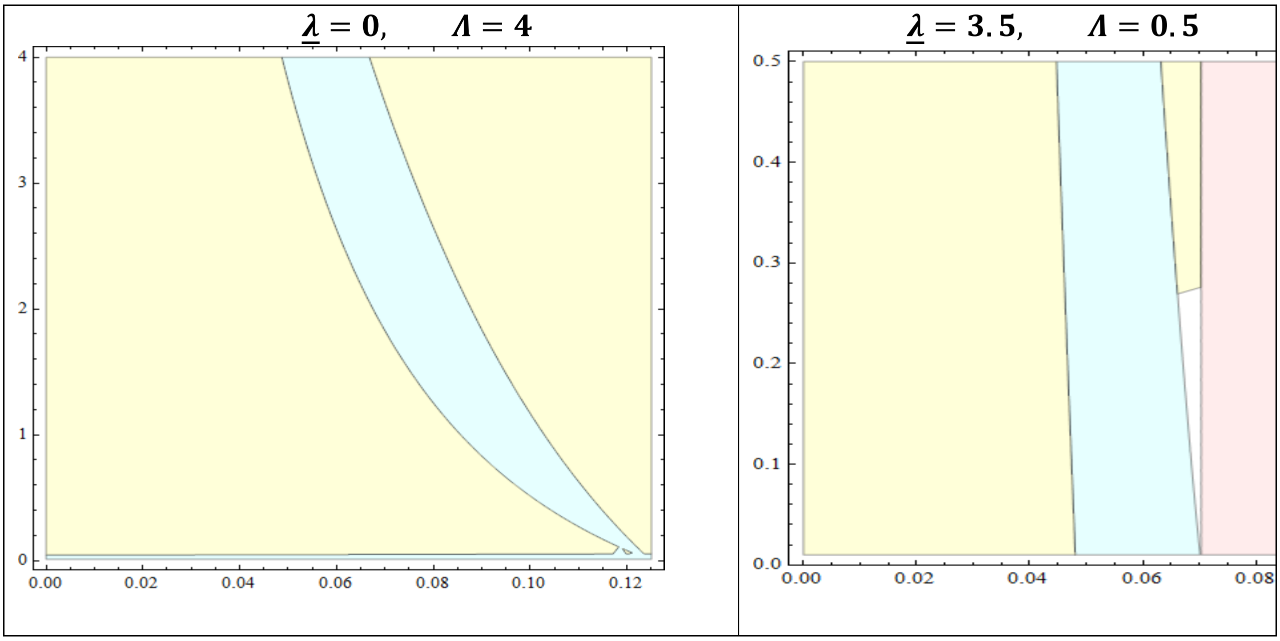
Figure 4.

($\underline{\lambda} = 2,\ \Lambda = 2$**)**



The interval between the first two vertical gray dashed-dotted lines on each panel shows the range of *F* values for which the *OS* produces higher consumer surplus than the currently used *PP* system. The first of these two lines corresponds to the *F* level at which the two systems are similar. Thus, the advantage of OS in terms of consumer surplus occurs for values of *F* for which the conventional argument of more products under OS no longer holds.

Figure 5.



The figure is drawn on the (F, Λ) space. The panel on the LHS represents the widest possible risk-aversion distribution while on the RHS panel the distribution is narrow. In light yellow (cyan) areas the *PP* (*OS*) produces higher consumer surplus. The pink area on the RHS panel is a zone of non-admissible values (the market collapses). The small white area on the right panel is due to imperfections in the area selection, due to inefficient number of decimals.

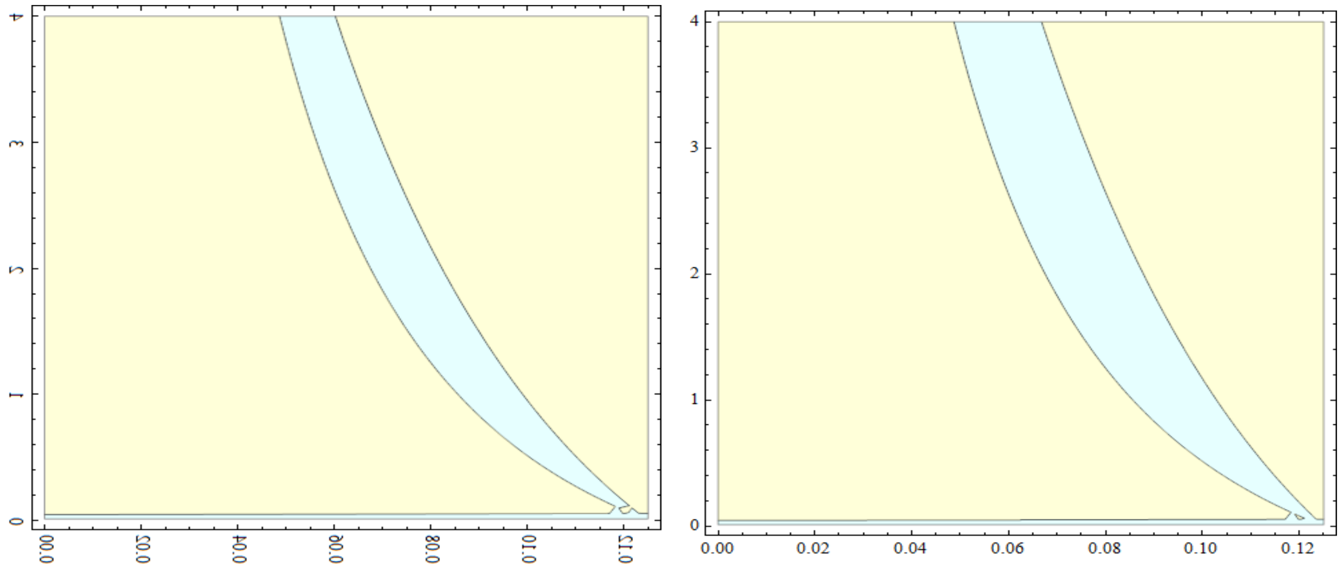
The figure shows that for every level of *F* the advantage of *OS* occurs for middle to high levels of risk-aversion dispersion. The lower border of the cyan surface represents combinations for which $w_1 = w_2$ and $T = 0$. If the figure were depicting surplus *per market*, all the surface above that line would have been cyan, indicating surplus dominance of the *OS*.

Finally, we compare total welfare under the two schemes. Total welfare has been calculated as the surface under the demand curve minus cost. The later is the fixed cost of production plus the cost of risk, *i.e.*, $C = F + \sigma^2 \int_{\underline{\lambda}}^{\lambda+\Lambda} \lambda d\lambda$

- **Proposition 4:** *The comparison of total welfare (TW) under the two schemes follows the same pattern as that of consumer surplus, i.e., for high and low (intermediate) levels of the fixed cost, the PP (OS) produces higher total welfare. The lower border of the area where the OS produces higher welfare is where T = 0, therefore coincides with the lower border of the area of combinations for which the OS yields higher consumer surplus. The higher border of the area where the OS produces higher welfare is* below *the upper border of the area where OS yields higher surplus, indicating that the TP tariff makes better risk management*

- **Proof:** The proof is numerical and is illustrated on the following figure. In all three panels, green-orange line is the value of F_H and together with the 2nd orange line to the right delineates the interval of total-welfare superiority of OS. The gray line dash-dotted line shows the value of F for which the two systems produce the same consumer surplus.

Figure 6.



Both panels are drawn on the (F, Λ) space. The LHS panel shows the areas of superiority of each system in terms of total welfare, wereas the RHS panel repeats the 1st panel of figure 5, showing areas where each system is superior in terms of consumer surplus. Again, the yellow (light blue) surfaces show combinations where the *PP* (*OP*) is superior.

5. Conclusions

In this work we considered a bilateral monopoly in a vertical chain where the downstream part (D) has to pay a fixed R&D for the development of a new product based on some basic innovation owned by the upstream part (Ph). The D faces uncertainty in that its R&D may not be successful and is risk-averse; for simplicity we have assumed that the Ph is risk-neutral. The Ph makes take-it-or-leave-it offers which the D may accept or reject.

Our main motivation was the comparison of two ID-protection systems: the current patent protection system (PP) which allows the Ph to exclude potential users of his innovation and the proposed Open Source (OS) system according to which anyone can use the patented good provided that, ***if successful in her R&D***, she will pay pre-fixed royalties to the Ph, according to the success of her product in the market. We interpret the *PP* as a two-part tariff pricing with the fixed part paid in advance and the *OS* with a linear pricing only based on royalties which, under both systems, constitute ex-post payments.

We found that for low levels of *F* or low levels of risk-aversion, the linear pricing provides more insurance and thus mitigates at least partly its inherent inefficiency due to double marginalization. As however the burden of the risk increases, either due to a higher amount of *F* being at stake or higher risk-aversion from D's part, the roles are reversed: the optimal two-part-tariff requires higher royalties in exchange for a negative fixed transfer. The latter never covers the entire value of *F*, it represents therefore a sort of ***joint venture***. Without the possibility of negative transfers, at high levels of risk burden the TPT collapses to a linear pricing scheme.

Considering many types of Ds differing according to their risk-aversion coefficient, we identified two incentives in the Ph's decision: by increasing the royalty the Ph sells insurance (Rey & Tirole, 1986) but at the same time loses potential profit due to double marginalization. Our main result is that for relatively low levels of *F* and/or of the width of the Ds' distribution the main argument in favor of using Open Source is valid: it provides greater market coverage reaching a larger portion of the Ds' distribution. However, for high levels of *F* (and/or large distributions of Ds) the picture changes because the optimal TPT involves a negative transfer coupled with royalty that is higher than that under linear pricing.

In all cases, both consumer surplus and total welfare depend on two factors: a) the per-market efficiency and b) the number of potential products. The system with the higher royalty is at disadvantage relative to a) and at advantage relative to b). The comparison is even more complex since the royalty may be higher or lower in one the other system (L or TPT), according to the value of *F*. However, the TPT produces higher coverage when *F* is high and therefore a marginal increase in D's market coverage matters more due to a *ceteris paribus* low participation. Also, the TPT performs better in avoiding double marginalization at low levels of *F* where market coverage is not a so important problem. While these two arguments point to TPT as more efficient, we find cases where the linear pricing produces higher welfare; in all those cases, however, the TPT implies a negative transfer and reaches more Ds.

Note however that, since all the welfare-related results are based on balancing two efficiencies—more products and better allocation of risk *versus* avoiding double marginalization—they must be taken with caution since the relative magnitudes of these efficiencies may crucially depend on some of the many simplifying assumptions of the model. While some work on relaxing assumption is still needed, the main mechanisms as illustrated by the model are clearly at work.

As mentioned earlier the analysis generalizes easily if—instead of only risk aversion—we distribute Ds according to the burden they suffer by risk. This equally implies different probabilities of success, different returns in case of success or different R&D costs. We believe that the analysis will be essentially the same, but have focused on risk-aversion because we interpret it as a negative index of entrepreneurship, the latter being to a large extent synonymous to willingness for risk-taking. Thus, in our model all projects have objectively the same social value and should be undertaken by a risk-neutral planner, therefore the undertaking of more projects should be synonymous to favoring entrepreneurship.

Finally, note the following extension: instead of considering a Ds' distribution with decreasing probability density (concave cumulative function) one may think of a uniform distribution of developers with an increasingly higher degree of risk aversion, for instance λ^{α} with $\alpha > 1$. Some preliminary work shows that our results remain robust, but tractability issues have not allowed us to give a full dexcription of the case.

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