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RSCAS 2020/61
Robert Schuman Centre for Advanced Studies
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EUI Working Paper **RSCAS** 2020/61

ISSN 1028-3625

Published in September 2020 by the European University Institute.
Badia Fiesolana, via dei Roccettini 9
I – 50014 San Domenico di Fiesole (FI)
Italy

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Abstract

In the context of standards development, the current mechanism of negotiation of FRAND royalties frequently brings to undesirable litigation. This is mainly due to the fact that a relevant part of the information concerning the standard, required to stipulate complete license contracts, is revealed only after the standard itself has spread in the market. In this respect, we propose a litigation-reducing algorithm to determine the FRAND level of the licensing royalty. Unlike the current negotiation mechanism, this algorithm can be defined ex-ante, so to increase contract completeness, because it includes a Bayesian-updating rule, able to address the presence of ex-ante uncertainty. We derive the algorithm from a generic oligopolistic-competition model, so to deliver characteristics of applicability to both price and quantity competition. Simulations in a linear-Cournot framework suggest the algorithm calculates FRAND royalties and may be usefully applied to real-life cases.

Keywords

FRAND Royalty, Standard Setting Organisations, Technical Standards.

1 Introduction[*]

The benefits related with the establishment of technical standards are extensive, both for firms and for consumers. Through standards tangible progress is achieved in the development of technologies impacting such different concepts as Smart Homes, Internet Cloud or Mobile Communications, whereas much more is to be done for Smart Cities, V2X communication, and other applications of the Internet of Things (IoT), including better medical care and environmental monitoring.[1] As a consequence, in the advancement of frontier technology, a role of great relevance is played by standard setting organisations (SSOs), which are formed by a multiplicity of firms in possession of intellectual property rights (IPRs) aiming at developing and establishing new technical standards. A list of SSOs provided by ConsortiumInfo.org counts 1120 organisations, giving contribution in key areas such as Artificial Intelligence (AI), Cloud Computing, Wireless and Mobile Communications and the Internet of Things.[2]

To guarantee adequate incentive to continuous innovation, most SSOs allow their members to earn a profit from the development of standards by charging standard-implementers a F/RAND (Fair, Reasonable and Non-Discriminatory) royalty.[3] To assess such a FRAND rate, each IPR owner needs to take account of multiple factors, such as the actual spreading of the standard across producers and of the standardised-item across consumers, as well as the real contribution of its patents to the creation of the standard. For this reason, there exists a natural temporal lag between the licensing of the standard and the assessment of the FRAND level of the royalty fee.[4]

On the other hand, standard-implementers may reject the value assessment required by innovators and the actual royalty becomes the outcome of negotiation or, in absence of an

[*]This research was developed in the context of the project "Innovation and Intellectual Property in the digital age", carried out by the Florence School of Regulation – Communications and Media of the European University Institute. The project is made possible thanks to the financial support of private companies, including Qualcomm Inc. The authors express their gratitude to Lapo Filistrucchi, Chiara Carrozza and Marco Botta for their comments on earlier versions of this article that helped to improve and refine the work. The usual disclaimer applies.

[1]In the field of medical care, for instance, Tian *et al* (2019) state that 'through the use of the clinical decision support system, doctors can give expert advice based on algorithms to improve the accuracy of diagnosis, reduce the incidence of missed diagnosis and misdiagnosis, and enable patients to receive timely and appropriate medical treatment.'

[2]The full list on the website is at the address https://www.consortiuminfo.org/links/#.XbnsL3jQjIX.

[3]Whereas we discuss the European conception of FRAND royalties, in American parlance SSOs refer to RAND royalties.

[4]For an extensive review on the working of SSOs, see Gandal and Regibeau (2014).

agreement, of lawsuits. In this respect, empirical evidence suggests that litigation over the FRAND level of the royalty is frequently occurring and related to significant welfare losses. Bekkers *et al* (2014) estimate that the likelihood of litigation of baseline patents is around 3 percent, but it becomes five times greater in the case of standard essential patents (SEPs), with a global frequency of litigation around 19 percent.[5] Bessen and Meurer (2009) calculate the private cost of patent litigation and, given the result of their evaluation, assert that litigation risk has a strong impact on private and social costs and should affect patent policy.

In light of these considerations the following issue appears to be key to both IPR owners and standard-implementers: is it possible to reduce the likelihood of patent litigation by improving the FRAND mechanism? Whereas the literature discusses concrete procedures to evaluate the FRAND level of a royalty, it remains a matter of investigation how to make use of them to reduce litigation. The value-added of this paper is to shed light on the issue by addressing four points: i) we investigate why licensing agreements cannot be immediately enriched with a FRAND assessment of the royalty; ii) we show that this fact determines contract incompleteness and creates scope for litigation; iii) we suggest a pioneering procedure to increase the degree of completeness of licensing agreements; iv) we provide a simulation on the working of this procedure to test applicability to real-life cases. More specifically, we show that steps forward to reduce litigation may be done by making use of a **royalty-fixing algorithm** based on a principle of Bayesian-updating; but two core conditions should be respected. First, the algorithm should be established *before* the standard is licensed, so that it can increase contract completeness. Second, the contract should enforce the periodic re-application of the algorithm *after* the standard has spread and new relevant information is acquired, so that the actual level of the royalty is determined (and eventually adjourned) *ex-post* on the basis of a rule established *ex-ante*. This ensures licensing on FRAND terms.

We extend our contribution by deriving such a royalty-fixing algorithm from a generic model of oligopoly - working in both quantity or price competition -, in which innovators cooperate within a standard setting organisation to develop a new standard, and implementers license the use of the standard to supply the market with a standardised-good. The SSO plays the role of a platform because, on the one hand, allows innovator cooperation and, on the other hand, interact

[5] Further studies discuss in details some very visible disputes in which massive SEPs holders and large amount of money are involved. For instance, Putnam (2014) addresses, among the others, *Oracle vs Google* and *Lucent vs Microsoft*, whereas Sidak (2016 a) analyses *Ericsson vs D-Link Systems* over Wi-Fi patent infringement.

with implementers to provide the standard. The model relies on a two-stage game enriched with uncertainty. In stage one, innovative firms and implementers bargain over the level of the royalty rate. Due to the uncertainty around the future success of the standard, the parties allow for a Bayesian updating mechanism. In stage two, each implementer pays the royalty and produces the standardised-good competing in a generic form of oligopoly against the other implementers. We assume subgame perfection, so that each firm is aware of the effect of each choice on future decisions.

The structure of the paper is as follows. Section 2 describes the main issues behind the stipulation of more complete contracts in the field of FRAND royalties and comments heuristically the working of our solution. Section 3 explains in analytical detail our solution making use of a model of generic oligopolistic competition to derive a royalty-fixing algorithm, which is enriched with a Bayesian-updating mechanism in section 4. Section 5 provides a simulation in the Cournot linear-logistic competition case. Section 6 concludes.

2 Description of FRAND terms and motivation of the paper

2.1 Literature review

There is a conspicuous number of contributions, including Chiao *et al* (2005), Gandal and Regibeau (2014), Lemley (2002), Parcu (2019), Sidak (2016 a, 2016 b), and Spulber (2018), clarifying the role of SSOs and the rules to observe for joining firms.[6] In this respect, the most controversial issue is represented by the prescription to license the standard on FRAND terms, since it provides guidance for IPR owners in the setting of the royalty rate without being rigorously defined.

The literature has attempted to shed light on aspects of FRAND royalties and provide

[6]This literature is a branch of the economics of innovation focusing on patents and patent value. Levin *et al* (1987), exploring the appropriability of R&D investment returns, observe that the presence of a legal patent system accounts only for a part of intellectual protection; since other sources of protection are represented by the lead time and the exploitation of learning advantages naturally accrued to the innovator. Pakes (1984) and Schankerman and Pakes (1985) show the data on patent renewal may be used to estimate the value of a patent. Sullivan (1994) analyses how to assess the value of the patents in the UK; Hall *et al* (2005) capture the impact of citations on the market value of a patent; Bessen (2008) estimates the value of patents in the US relying on renewal data, controlling for patent and owner characteristics. The assessment of patent values is more difficult in the case of complex product since it must take account of the innovative contribution of each patent. Putnam (2014), admitting the high skewness of the patent value distribution, proposes to relate the impact of each patent to its value.

concrete procedures to assess their value. Swanson and Baumol (2005) propose the application of the Efficient Price Component Rule (ECPR) as an instrument to capture the impact of each patent to the development of the standard; such impact, in turn, represents a suitable basis for calculating the royalty rate. Layne-Farrar *et al* (2007) argue the former rule is more adapt to identify only a RAND level of royalty because it disregards fairness, and instead suggest to adopt a Shapley Value (SV) approach. Dehez and Poukens (2013), discussing the Shapley Value, observe some patents are technologically required for the development of the standard because they cannot be invented around. These standard-essential patents procure the owners a veto power, since the absence of any one such patent is sufficient to prevent the development of the standard. Thus, the authors suggest to treat all standard-essential patents as equally contributing to the development of the standard, independently of their intrinsic innovative value.[7]

These contributions discuss concrete methods to calculate the level of remuneration of each IPR owner according to the innovative contribution of its patent portfolio to the development of the standard. In other words they provide a rule of allocation of the royalty across all standard-developers; whereas the determination of the total fee paid by implementers is obtained in an indirect manner, since it is determined as the sum of all innovator-specific fees.

Our paper takes a different route respect to this branch of the literature as we address directly the issue of evaluating and implementing a total FRAND royalty. We add to previous contributions by providing a discussion on the total level of the royalty; in particular, we show that an indirect calculation may fail to be compliant with the FRAND commitments and why a direct assessment is also required. Finally, we show how to implement such a FRAND rate through an enforceable contract, so as to curb litigation.

2.2 Licensing on FRAND commitments

Indications about the meaning of FRAND commitments derives from the jurisprudence. From the innovator perspective, the amount of royalty is FRAND if it takes account of the innovative

[7]The difference between strong and weak patents is thoroughly discussed by Farell and Shapiro (2008). Kamien and Tauman (1986) distinguish between fees and royalties and the impact on profits of the patent holder. The presence of standard-essential patents is related to holdup issues. Shapiro (2000) discusses this problem referring to the case of patent thickets, that is when an implementer is required to obtain license to operate from multiple patent holders.

contribution to the development of the standard; whereas from the implementer perspective, a FRAND level of royalty should be set according to the degree of commercial success of the standard, since only highly successful standards may produce high profits for implementers and, in turn, be consistent with high royalty payments.[8] Innovative contribution and standard success may be measured, respectively, by the impact of each patent on the development of the standard and the demand for the standardised-product supplied by the implementers; however such measures require information which is unknown at the innovation stage: the assessment of the former follows a technical, time-consuming analysis, whereas the determination of the latter can occur only after observing the actual level of sales in commercial markets.[9] For this reason, it is common practice for an IPR owner to negotiate with the implementing firms, in a bilateral manner, the FRAND fee for the use of its patent only *ex-post*, that is when information becomes available. When a license contract is signed, the IPR owner grants the implementer the permission to use its share of patents involved in the standard; and each implementer needs to sign as many license agreements as the number of IPR owners to make use of the standard without patent infringement risks.

One main issue related with the *ex-post* determination of the royalty is that the parties cannot stipulate *ex-ante* a complete contract.[10] This means that IPR owners often cannot obtain the desired level of remuneration and, in fact, the FRAND terms are frequent object of litigation. In principle, the royalty could be fixed *ex-ante* in a context of full certainty, which would imply that the parties knew in advance the future commercial success of the standard, the innovative contribution of each patent and were thus able to derive a FRAND fee. In the uncertain reality, however, such information becomes available much later and, what mostly counts, after the beginning of the use of the standard by implementers.

Allowing innovators and implementers to sign complete contracts *ex-ante* must pass through a way to overcome the presence of uncertainty. A possible step forward may be taken if the parties agreed *ex-ante*, rather than on a specific royalty rate, on a general royalty-fixing algorithm with

[8] Judge Robart, in *Microsoft Corp. v. Motorola, Inc.*, 2013 WL 2111217 (W.D. Wash. April 25, 2013), notes that *"the parties in a hypothetical negotiation would set RAND royalty rates by looking at the importance of the SEPs to the standard and the importance of the standard and the SEPs to the products at issue"*.

[9] The impact of a patent on the development of the standard is captured, to some extent, by the market price of that patent. However, it is necessary to observe that there may be exceptions: even a low-price patent may present a high innovative contribution if it involves a technology without which the standard cannot be implemented (i.e. it constitutes a standard essential patents).

[10] As common in the literature, we refer to *ex-ante* as the time after which all investments in R&D have been made and all patents have been obtained, but before the standard is licensed to implementing firms.

a mechanism of Bayesian-updating, where the algorithm-input is represented by some measure capturing the commercial success of the standard, such as the number of implementing firms, the number of products sold in commercial markets, the amount of revenue dollars in aggregate (or on average), price per unit and the like, and the algorithm-output is the level of the royalty. If this solution is adopted, the level of the royalty is still revealed *ex-post*, together with the success of the standard, but the fixing-rule is agreed upon *ex-ante*, so as to increase contract completeness ensuring licensing on FRAND terms.[11] The Bayesian mechanism could be re-applied periodically, where the period is be specifies by the contract, to take account of the evolutionary dynamics of the demand of the standardised-items, so that the royalty is always related to the commercial success of the standard.

With such a mechanism of Bayesian updating the parties could overcome the fundamental uncertainty over the future commercial success of the standard. However, another source of uncertainty may limit the possibility for *ex-ante* royalty-setting: if the innovative contribution of each patent to the development of the standard cannot be estimated in an accurate manner *ex-ante*, the innovators are unable to assess a FRAND remuneration for those patents.[12] It is convenient to observe, from a theoretical point of view, the ownership of highly innovative patents - eventually SEPs - should impact the distribution of the royalty in favour of those patent holders; however it seems safe to state that the total amount of the fee paid by implementers, given by the sum of all innovator-specific royalties, should not be affected by the allocation of SEPs across innovators, but rather by other measures concerning the commercial success of the standard and the standardised-items. **In other words, the ownership of SEPs should be relevant in terms of royalty redistribution, rather than total amount.**

In order to respect this theoretical consideration, an innovator owning SEPs should charge higher royalties and coordinate with other innovators so that the total value of the fee is unchanged for implementers. However, when standards consists of hundreds, possibly thousands, of patents, such coordination seems unfeasible due to the large number of negotiations between all innovators and implementers. In the light of this fact, a more natural solution is to shift the terms of agreement from the current bilateral contract, focused on the innovator-specific royalty for the use of its patents, to a multilateral approach, in which every implementer bargains with

[11] We shall develop this idea in section 4.1.

[12] The ownership of highly innovative patents or of SEPs allows innovators to negotiate higher royalties. For a thorough discussion on SEPs and hold-up issues related to higher royalties, see Shapiro (2000).

the totality of IPR owners at once, and the target becomes the total amount of the fee to pay for the use of the standard. After the standard is developed, but before its distribution to implementing firms, IPR owners could provide one agent with power of attorney and give mandate to negotiate with each implementer a Bayesian-algorithm to fix the total fee that that implementer is to pay for the full use of the standard. On the basis of such negotiation, a complete license contract may be stipulated *ex-ante* between the totality of IPR owners and each implementer - or even with another agent representing more implementing firms, eventually belonging to the same market segment - with clear indications, described by the Bayesian algorithm, about how to fix the FRAND standard-fee; whereas the allocation of SEPs will determine *ex-post* the distribution of such fee across IPR owners.[13]

There are at least three reasons to believe that the multilateral Bayesian approach we propose may be superior to the current bilateral negotiation. First, in the bilateral approach there is no coordination among innovators and no control over the total fee for the use of the standard, since it is freely determined as the sum of all innovator-specific royalties. In fact, if the total fee is excessively large, implementers may have an extra-incentive to litigate with IPR owners, especially the larger ones, since they plausibly represent a large share of the royalty cost. The multilateral approach, on the other hand, allows full control over the total royalty fee, so that compliance with the FRAND commitment is ensured also from the implementer perspective. Second, the multilateral Bayesian approach allows to overcome *ex-ante* the presence of uncertainty, for instance about the future commercial success of the standard, and to stipulate complete contracts, so to curb litigation. Third, it seems that the multilateral approach may go along the way discussed in the hold-up literature as a useful instrument to reduce the risk of hold-up situations, since each implementer obtains permission to use all the standard-involved patents at once.[14] All in all, the presence of such a complete contract is likely to have a large impact on FRAND litigation.

Let us stress that, while **we focus on the determination of the total level of the roy-**

[13]We are aware of the fact that the determination of such an agent may be made difficult by heterogeneity in the innovator group, which may include firms, universities and other research organisations. We consider, however, the mild assumption that all these subjects share some homogeneity at the objective-level, so that any agent able to bargain high royalties may be a suitable candidate. In this respect, the case of massive presence of nonprofit research organisations, aiming at charging low or zero royalties, is not in our interest because it is unlikely to be associated with *ex-post* litigation.

[14]Analysing this point in more details goes beyond the scope of the paper. See Shapiro (2000) for a thorough discussion about hold-up issues and antitrust implication on patent pools.

alty as the primary issue, compliance with the FRAND terms may be assessed at two further levels, concerning the distribution of total royalty among IPR owners and among implementers. As for the latter, it does not appear to require active control, in fact it is achieved in a natural way by markets. According to their size, implementers produce the standardised-item and sell it on the goods market, normally paying the royalty to innovators per item sold. The former, on the other hand, represents a serious issue. The literature has proposed some interesting clues for finding a solution, such as the Shapley Value and the Efficient Price Component Rule but, if they do not seem to be fully satisfactory, innovators may agree on some different rule before disclosing their patents to the SSO, provided that a FRAND distribution of the royalty should be anyway determined according to the innovative contribution of each innovator. While this matter deserves thorough discussion and may represent a critical focus for further research, if the total amount of the royalties is FRAND, also the fair distribution among innovators becomes more tractable.[15]

3 Deterministic model

Let us move to the theoretical set-up on which the parties may rely to define a FRAND royalty-fixing algorithm.[16] We consider an oligopolistic, partial equilibrium model of development of a new standard in which there are two main groups of players: innovative firms, which are willing to cooperate and establish a new standard, and implementing firms, which acquire the right of using the standard by paying a royalty fee and supply the market with a standardised good to earn profits. Let us consider n cooperative innovators. The cooperation rules are set by an independent player, a standard setting organisation (SSO), which obtains the right to use the patents of all innovators to develop the new standard. In this framework, the SSO behaves as a platform connecting two sides of the same market: on the one hand, innovators cooperate through the platform to create the new standard, on the other hand, producers acquire the

[15] We plan to discuss and apply a similar adjustment mechanism to royalty splitting among innovators in a future companion paper, see footnote 22.

[16] The algorithm is to apply before the standard is licensed. In the case of standards with multiple generations, such as USB 2.0 - 3.0 or 4G - 5G, we think that the algorithm should be re-applied before the new version is made public, as if it were a distinct standard, for a two-fold argument. On the one hand, each standard generation might involve new patents, new IPR owners and new implementing firms; and the innovative contribution to the development of the standard may shift from some innovator to some other. On the other hand, there usually exists an extended period of time in between the development of two generations, within which many market conditions may change to a relevant extent. For these reasons, a re-negotiation of the licensing agreement may be required to enforce compliance with the FRAND terms.

standard from the SSO to produce the standardised good.[17]

The royalty rate paid by implementers per unit of standardised good, denoted by r, is divided across innovators so that:

$$r = \sum_{j=1}^{n} r^j \tag{1}$$

where r^j is the unit royalty earning for innovator j. In addition to the royalty payment, we assume the standardised-good production process requires the use of a bundle of inputs, e.g. labour, in homogeneous quantities. This is equivalent to consider constant marginal costs c, equal to the sum between r and the component relative to use of the input, measured by $\bar{c}$. That is:[18]

$$c = \bar{c} + r \tag{2}$$

3.1 Production stage

The model lays out on a two-stage structure. At the innovation stage, the innovators bargain with the implementers over the total royalty rate. At the production stage, implementers supply the market with the standardised-good. We assume sub-game perfection and solve the model with backward induction.

Let us consider q implementers in the goods market. In stage two implementer i maximises the level of profit:

$$\max_{a_i} \quad \pi^i = \pi^i[c(r), a_i, \mathbf{a}_{-i}] \tag{3}$$

where π^i is i's profit, a_i is the variable of choice of producer i (output in Cournot or price in Bertrand, in which we assume all firms supply differentiated products), and $\mathbf{a}_{-i}$ is the vector describing the choice of all rivals. In equilibrium, for each firm we have the derivative of i's profits with respect to i's choice is equal to zero, that is, $\pi^i_i = 0$.

[17] In our set-up we implicitily assume that innovators and implementers form distinct groups. However, we are aware of the fact that a firm may be vertically integrated, meaning that it engages in research and development activities in order to implement and compete in the downstream goods market, and thus belong to both sets of players. While such vertically integrated firms may be more naturally oriented towards other standard-setting institutions like Silos, we think that excluding their presence from our analysis does not appear to be harmful, since we concentrate on the cases of litigation emerging from distinct groups of firms with opposite interests.

[18] We are assuming symmetric implementing firms, that is, they share the same pre-innovation technology $\bar{c}$ and are charged the same royalty fee r. Since the imposition of the same royalty rate may be justified only when firms supply similar products, our set-up refers to the case of implementers operating on the same market. A multi-market analysis requires differentiated royalties.

To discuss stability, let us consider, for any firms i and j, the following assumption:

Assumption 1. $\pi^i_{ii} - \pi^i_{ij} < 0$

The second-order condition requires $\pi^i_{ii} < 0$, whereas the cross derivative π^i_{ij}, measuring the impact of firm j's choice on firm i's marginal profitability, is negative if actions are strategic substitutes (Cournot) and positive if they are strategic complements (Bertrand).[19] Leahy and Neary (1997) show the following result:

Lemma 1. *Under assumption 1, in a symmetric q-firm oligopoly the equilibrium is stable if, and only if:*

$$\Delta \equiv \pi^i_{ii} + (q-1)\pi^i_{ij} < 0$$

This lemma provides a necessary and sufficient condition for the oligopolistic equilibrium to be stable. Moreover, in the stable symmetric-equilibrium, denoting the amount of output of a firm by y, we can manipulate the total derivative of any firm's first-order condition into the following equation:

$$\frac{da}{dr} = \frac{y_i}{\Delta} \tag{4}$$

This condition describes the sign of the relationship between the level of the royalty set at the innovation stage and the decision of each firm at the production stage. More specifically, given that y_i (the derivative of output with respect to i's choice) is equal to one in Cournot and negative in Bertrand and that Δ is always negative by lemma 1, an increase in the royalty rate produces either a reduction in output amount with quantity-competition or an increase in price level with price-competition.

3.2 Bargaining stage

In stage one the innovators bargain with the implementers over the total level of royalty. We assume the two groups are represented by two distinct agents aiming, on the one hand, at increasing the revenues from the royalty payments for the use of the standard and, on the other hand, at maximising industry-level profits from the supply of the standardised-good.[20] The level

[19] Proof of this fact comes from the total derivative of firm i's first-order condition.

[20] Let us stress that the assumption of two agents is necessary to the model only to a partial extent. In particular, while we require the presence of an agent on the innovator side, since we aim to increase coordination

of the royalty r results from the maximisation of the following Nash bargaining :

$$\max_{r} \quad B \equiv [R(r)]^{\beta}[\Pi(r)]^{1-\beta} \tag{5}$$

subject to the holding of the first-order conditions in stage two, where $\beta \in [0,1]$ is the parameter capturing the bargaining power of the innovators; R is revenue from royalty payments, given by the product between the royalty rate per unit of output r and the industrywide supply of standardised-good; and Π is industrywide profits defined as the sum of all implementer-specific profits ($\Pi = \sum_{i=1}^{q} \pi_i$).[21] The Nash bargaining problem is a standard way to analyse the outcome of negotiations. In our context of royalty payments, the maximisation problem may be interpreted as the parties trying to maximise together the level of producer welfare related to the use of the standard denoted by B; but the redistribution of such welfare between innovators and implementers depends on their own bargaining power.

Since both price and output are determined by stage-two first order condition, functions R and Π depends only on r. The bargained level of the royalty rate arises from the first order condition $B_r = 0$, given the holding of the second order condition $B_{rr} < 0$.

4 Model enriched with uncertainty

4.1 Introduction of time

The model of section 3 describes the determination of the royalty rate in a deterministic set-up, since uncertainty around the future success of the standard is not taken into account. Let us consider a generic number of periods, say T, and allow for *inter*-period demand change. For

among IPR owners, the presence of an agent on the implementer side only serves model tractability. In principle, we may have had the innovator agent carry as many negotiations as the number of implementing firms by applying the present model repeatedly.

[21] As observed by Binmore *et al* (1986), the presence of the coefficient β introduces an asymmetry in the bargaining process. In particular, the authors write: 'First, note that there are several sources of asymmetry in the bargaining power. These include the above-mentioned asymmetries in preferences, disagreement points, and the bargaining procedure; and perhaps there are also asymmetries in the parties' beliefs about some determinant of the environment.' Moreover, Bowles (2009) observes that bargaining is a costly activity, including cost of delay and impatience, and the cost for both parties needs not be equal; more specifically, the author shows that higher rates of impatience are related to lower bargaining power. Furthermore, in this specific context the bargaining process occurs in the presence of a standard setting organisation, which may be oriented towards a specific group of economic agents and influence the distribution of bargaining power. Spulber (2018) discussion of SSO voting practices is particularly relevant to this specific issue.

each implementer i, we have:

$$y_t^i = f_t^i(p_t^i, \mathbf{p}_t^{-i}) \tag{6}$$

where, in each period t, the relationship between the firm-specific output level depends on the price vector according to the function f_t^i, changing over time, capturing the evolution of consumer preferences for firm i's standardised-product. This means that, if all firms charge the same prices for two periods, the amount of sales of those firms needs not be constant. The exact form of function f_t^i is revealed by consumer preferences at time t and is thus unknown at earlier periods. Due to this presence of uncertainty, the period-specific royalty rate must rely on expectations concerning the period-specific level of consumer preferences. At the beginning of the following period, however, a comparison on the evolution of consumer preferences may point out a significant difference between expectations and reality; in this case, expectation-based royalties are not consistent with the FRAND terms and royalty-updating is thus required. In the following section we address this issue by deriving a Bayesian updating rule able to correct for expectation errors.[22]

4.2 Demand uncertainty

The production stage is not affected by uncertainty and thus is analogous to the one analysed in section 3. Since this stage spans over T periods, implementers in each $t \in \{1, ..., T\}$ aim at increasing profits by selecting an optimal choice a_t^i as follows:

$$\max_{a_t^i} \quad \pi_t^i = \pi_t^i[c(r_t), a_t^i, \mathbf{a}_t^{-i}] \tag{7}$$

Given symmetric firms and symmetric equilibrium, for each period t the first order condition $d\pi_t/da_t = 0$ delivers the optimal choice a_t^*. The solution-vector of problem 7 is thus $\{a_1^*, ..., a_T^*\}$.

At the innovation stage the success of the standard is still unknown. For this reason the agents of implementers and innovators, rather than agreeing on a royalty rate, establish a royalty-fixing

[22]A further dimension of uncertainty regards the ownership of SEPs because, *ex-ante*, the standard setting organisation is not able to clearly disentangle the innovative contribution of a patent from the innovative contribution of the other patents. At the innovation stage each innovator self-declares the ownership of either essential or non-essential patents on the basis of self-assessment. *Ex-post*, however, the standard setting organisation is able to test such self-declaration and, after a certain period of time, the real distribution across patents of the innovative contribution may become common knowledge. We plan to explore an *ex-post* Bayesian adjustment mechanism to royalty splitting among innovators in a successive paper.

algorithm as discussed in section 2. On the one hand, this algorithm calculates the period-specific royalty rate on the basis of the expected level of success of the standard for that period. On the other hand, at the end of the same period, expectations are compared with the observed level of success of the standard, adjusted and re-applied to calculate the royalty rate to charge in the next period. In other words, the royalty-fixing algorithm works as a Bayesian-updating rule able to take account of additional information around the success of the standard.[23] The bargaining problem of innovators and implementers, regarding all commercialisation periods, is solved at the innovation stage; thus for all $t \in \{1, ..., T\}$ we have:

$$\max_{r_t} \quad B \equiv [R_t^e(r_t, y_t)]^{\beta} \, [\Pi_t^e(r_t, y_t)]^{1-\beta} \tag{8}$$

where functions R_t^e and Π_t^e, denoting expected royalty-revenues and implementer profits at time t, depend on both the evolution of standardised-good demand and the royalty rate. By calculating the derivatives, the parties can find a vector of royalty payments $(r_1^*, ..., r_T^*)$.[24]

5 The Cournot linear-logistic case

We shall provide the model with some qualification in order to discuss specific results. Let us consider a Cournot competition with linear demand, $p_t = A_t - Y_t$ ($A_t > 0$), where A_t is the parameter capturing consumer preferences; and symmetric firms, so that implementers share the same cost structure: $\forall i, j \in \{1, ..., q\}, c_t^i = c_t^j = c_t$. During the production phase, implementer i aims at increasing profits from the sale of the standardised-good as follows:

$$\max_{y_t^i} \quad \pi_t^i = (p_t - c_t) y_t^i \tag{9}$$

where π_t^i is i's profit at time t. The first order condition is:

$$\frac{\partial \pi_t^i}{\partial y_t^i} = p_t - c_t - y_t^i = 0 \tag{10}$$

[23]Our period is solely theoretical and refers to the moment in which new information about the success of the standard becomes available. Relating this period to calendar time requires the analysis of standard-specific characteristics and is out of our scope. In general, the shorter the period the more frequent the updating, but also the more cumbersome.

[24]The full identification of problem 8 requires the parties to converge on common expectations. In fact, if any one party could appeal against the formulation of expectations, that party would have an argument to litigate over the level of the royalty rate. In section 5 we simulate the working of this approach by referring to specific functional forms.

From the first-order condition of each producer at each time t we can derive the equilibrium level of output for each firm:

$$y_t^i = y_t^j \equiv y_t = \frac{A_t - \bar{c} - r_t}{q+1} \tag{11}$$

This equation states the equilibrium is symmetric and variations of output from one period to another can be produced by either a change in the royalty rate and the evolution of consumer preferences. Moreover, a result well-known from the literature (see for instance Leahy and Montagna, 2001) is the following:

Lemma 2. *Along the locus described by first-order condition 10, the profit function can be rearranged as* $\pi_t = y_t^2$.

Let us consider next the innovation stage. Innovators and implementers allow for a Bayesian royalty updating due to demand uncertainty. The objective function of the former group is expected royalty-revenues, given by the product between the royalty rate and industrywide output, whereas implementers pursues maximal expected profits. Given the one-to-one relationship between profits and output described in lemma 2 we can simplify the bargaining process on the implementers side as follows:[25]

$$\max_{r_t} \quad B \equiv (E[r_t Y_t])^{\beta} \, (E[Y_t])^{1-\beta} \tag{12}$$

in which implementers aim to increase the level of standardised-goods to supply to the market. The solution of problem 12 is given by:

$$r_t = \frac{\beta}{1+\beta}(E(A_t) - \bar{c}) \tag{13}$$

describing the algorithm to apply in each period to fix the period-specific royalty rate. First, let us observe that equation 13 prescribes an alignment of interests between the two groups due to the fact that the royalty rate is an increasing function of consumer preferences. On the one hand, implementers desire consumer preferences to be as high as possible because of the greater flow of sales - and profits - deriving from the standardised-good production. On the other hand, also innovators have the incentive to increase the quality of the standard, since

[25] The bargaining process may be thought of as a sequential procedure in which innovators propose a baseline agreement, implementers suggest some modification and both parties, at the end of the process, sign a binding contract reporting the value of the royalty as well as the updating rule.

high-quality standards are more likely to be related with highly demanded products and, thus, with higher royalty rates. Second, the level of the royalty depends on expectations around the demand for the standardised-good. If reality departs significantly from expectations, the royalty rate may become either excessively costly or economical for implementers, and compliance with the FRAND terms may be put at risk. This criticism may be addressed by allowing for periodic royalty-updating. Let us explore this issue by considering a logistic evolution for the preference parameter A_t. In this case the dynamics of the demand for the standardised-good is rapidly increasing at the launch and then stabilises around a maturity level. In our discrete-time setting the logistic map is given by $A_t = kA_{t-1}(1 - A_{t-1})$, where $k \in \mathbb{R}$ is the parameter capturing the rate of growth and A_t belongs to the interval $(0, 1)$.[26] Figure 1 depicts the logistic evolution of preferences in the first 5 periods considering the initial state $A_1 = 1/2$.

At the bargaining stage innovators and implementers reach common expectations around the evolution of preferences. Despite the great freedom around the functional form to adopt, for explanatory purposes we compare the following ones: *i)* $E[A_t] = A_{t-1}$, that is, preferences are expected to be constant over time, and *ii)* $E[A_t] = bA_{t-1}(1 - A_{t-1})$, in which preferences are expected to grow logistically and b generally differs from the true value k. Figure 2 depicts the outcome of the two rules considering $E[A_1] = A_1 = 0.5$ and $b < k$ (in this case, initial expectations are correct and confirmed by reality but, over time, preferences grow more than expected). The dashed line represents rule *i)* and the dotted line shows rule *ii)*, whereas the continuous line is the real evolution of preferences. As it can be seen, in this simulation the latter rule, presenting a rapid growth, is more able to replicate the evolution of preferences in the initial phase, however, it does not assure convergence to the maturity level; whereas the former rule performs better afterwards, when the change in the preference parameter over time is weakened.

Lemma 3. *If consumer preferences converge to maturity level, expectation-operator* $E_t[A_t] = A_{t-1}$ *allows expectations to converge to the same level.*

Remarkably, the expectation-operator may also be formed by the combination of other functions,

[26] The logistic map may produce very different evolutions depending on the value of the parameter k, spanning from deterministic to chaotic dynamics. For instance, $k \in (2, 3)$ describes a dynamics converging to $(k - 1)/k$, whereas for $k = 3$ convergence is replaced by an orbit between two values. In our simulation we shall refer to $k = 2.5$ since it produces an evolution of rapid growth at the launch and of stabilisation afterwards. Such an evolution is shown in figure 1. For a thorough discussion of the dynamics related to the logistic map see May (1976).

applying for example rule *ii*) for the first periods and rule *i*) afterwards, that is, when a quasi-constant evolution is more plausible. This consideration may represent an interesting cue for further research.

6 Concluding remarks

In the framework of standards creation we develop an original way to calculate total fair, reasonable and non-discriminatory (FRAND) royalties. As of today, the FRAND level of royalty is established by innovators *ex-post*, that is, after the development of the standard and during the commercialisation of the standardised-good; this allows a desirable adjustment of the level of the royalty to the level of demand for the standard. However, it entails the fact that the FRAND level of royalty cannot be well-designed *ex-ante* (before the commercialisation phase) through the stipulation of a complete contract. Empirical evidence suggests that the lack of an enforceable contract results in a high litigation rate between implementers and innovators. This issue represents a critical drawback, since it may considerably affect the incentive to innovation, the cost of production of the standardised-goods and the diffusion of the standard across society.

In the paper we address this issue providing a two-fold contribution. First, we discuss the current mechanism of determination of the FRAND level of royalty. A thorough discussion allows to highlight the main criticalities of the current approach, which may be summarised by the lack of coordination among economic agents and the *ex-post* determination of the royalty. Second, we tackle the issues by proposing an alternative approach. On the one hand, we argue for the introduction of a bargaining process - involving innovators, implementers and the standard setting organisation - to set the royalty rate implementers have to pay to comply with the standard, so to enhance coordination among innovators. On the other hand, we suggest the adoption of a Bayesian updating for the royalty rate, which can be determined *ex-ante* at the innovation stage. Such an alternative approach is presented, at first, in a theoretical framework with generic competition form (either Cournot and Bertrand) and demand function, then we apply the analysis to the linear-logistic Cournot case. For this application we derive a consistent Bayesian updating for the royalty rate, so that the royalty level set *ex-ante* does not diverge from the evolving FRAND level.

Our work may address a large gap in the literature because it discusses one relevant issue providing a theoretically-grounded solution. However, this theoretical framework may be still enhanced. First, it is opportune to test the empirical validity of the model, using specific functional forms and parameters, if one wants to proceed to real-life applications. Second, while we focus on how to enforce the FRAND total level of the royalty, further effort, along the same line, should be spent to elaborate an *ex-ante* FRAND method to redistribute the royalty rate among the innovators of the standard. Some interesting insight along this line may be delivered by considering the standard setting organisation as a cooperative platform, and applying a cooperative rule of distribution, such as a Bayesian-adjusted *ex-post* Shapley Value, to determine the contribution of each cooperative member. Third, the *ex-ante* uncertainty surrounding the ownership of standard-essential patents suggests there is scope for the definition of an insurance contract covering the royalty payments. These research lines represent very interesting possible developments.

Appendix

Sign of π_{ij}

At the production stage the first-order condition of firm i is such that $\pi_i = \pi_i(r, a_i, a_{-i}) = 0$. By totally differentiating such first-order condition we obtain:

$$\pi_{ii} da_i + \pi_{ij}(q-1) da_j - y_i dr = 0$$

Consider now the case $dr = 0$. We have:

$$\pi_{ij} = -\frac{\pi_{ii}}{q-1}\frac{da_i}{da_j}$$

from which, given that π_{ii} must be negative, the cross derivative of firm i's profits with respect to firm j's decision is negative if second-stage choices are strategic substitutes and positive is they are strategic complements.

Equation 4

At the production stage the first-order condition of firm i is such that $\pi_i = \pi_i(r, a_i, a_{-i}) = 0$. By totally differentiating such first-order condition we obtain:

$$\pi_{ii} da_i + \pi_{ij}(q-1)da_j - y_i dr = 0$$

Consider now a uniform shock to the symmetric equilibrium such that $da_i = da_j = da$. Thus:

$$[\pi_{ii} + (q-1)\pi_{ij}]da - y_i dr = 0$$

from which, considering $\Delta = \pi_{ii} + (q-1)\pi_{ij}$, we have equation 4.

Lemma 2

From condition 10 we obtain $p_t - c_t = y_t^i$. Plugging such condition into the profit function $\pi_t^i = (p_t - c_t)y_t^i$ concludes the proof of the lemma.

Lemma 3

If consumer preferences converge to a given value, for all $\epsilon > 0$ there exists $\bar{t}$ such that, for all $t > \bar{t}$, we have:

$$|A_t - A_{t-1}| < \epsilon$$

Since, by definition, $E[A_t] = A_{t-1}$, for the same value of ϵ we have:

$$|A_t - E[A_t]| < \epsilon$$

as we wanted to show.

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Figures

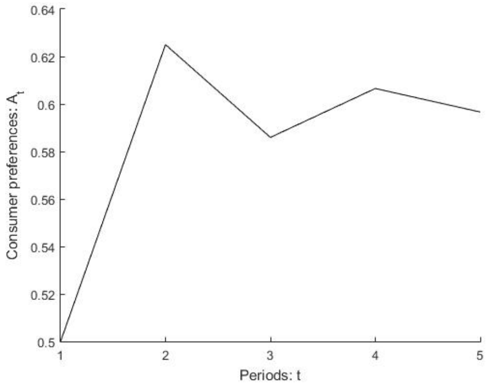

Figure 1: Real evolution of consumer preferences (k=2.5)

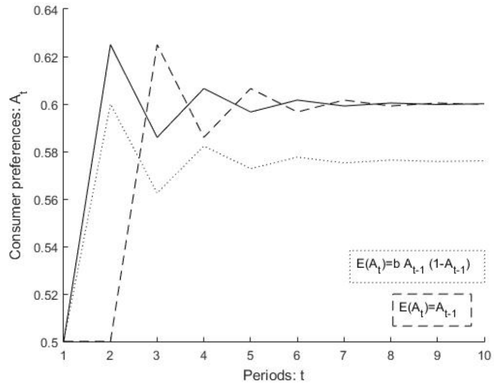

Figure 2: Expected evolution of preferences (k=2.5, b=2.4)

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With the support of the Erasmus+ Programme of the European Union

The European Commission supports the EUI through the European Union budget. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.