How to license SEPs to promote innovation and entrepreneurship in the IoT*

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Abstract: The Internet of Things (IoT) relies heavily on wireless communication technologies, which are covered by thousands of standard-essential patents (SEPs). Numerous applications of IoT technologies are being developed, frequently coming from entrepreneurial firms. The high degree of fragmentation on the side of device makers raises the question of how—i.e., on which level of the value chain—SEPs should be licensed. Device makers prefer upstream licensing, allowing them to purchase fully licensed modules, while SEP holders tend to favour licensing at the device level. I present empirical evidence on the matter from a qualitative study comprising interviews with 18 individuals from 12 firms of different sizes and industries, including device makers and SEP licensors. The focus lies on the perspective of entrepreneurial firms. I also review and discuss arguments presented in the literature. I find that device-level licensing poses serious problems to device makers, in particular to SMEs. The main problems are: A lack of resources and pertinent legal and technical competence, precluding fair negotiations with licensors; high transaction costs due to a high degree of industry fragmentation; and uncertainty regarding cost and patent clearance. As a consequence, device-level licensing would likely have a chilling effect on innovation and entrepreneurship in the IoT. Policy makers should ensure that IoT SEP licensing is simplified. They should commission studies on the feasibility of licensing and price differentiation higher up in the value chain, and on the aggregate cost of developing the main standards. Adding to those formulated by the SEPs Expert Group, I propose two additional principles for IoT SEP licensing: Licensing at a value chain level where transaction costs are minimal; and licensing in a way that promotes downstream innovation and entrepreneurship.

Keywords: Internet of Things, standard-essential patents, licensing, innovation, entrepreneurship

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1. Introduction

The question of how to license standard-essential patents (SEPs) for mobile communication technologies is the subject of intense debate among policy makers, industry players, and scholars (e.g., Geradin, 2020; SEPs Expert Group, 2021). The heterogeneity of players and applications and the projected explosive growth of the Internet of Things (IoT) have given new momentum to the discussion. The most contentious issues are the amount and determination of royalties and at which level of the value chain royalties should be charged.

Traditionally, for mobile phones and network equipment, makers of devices that implement SEPs are telecommunications firms, are relatively few in number and typically large—manufacturers of baseband processors, handsets, or equipment. In the IoT, this is no longer the case. Device makers (often referred to as "implementers") come from diverse industries, are numerous, and frequently small and medium-sized enterprises (SMEs) or startups. These differences have implications for SEP licensing, both for the calculation of royalties and for the choice of the licensing level. SEP holders tend to favour device-level licensing, while implementers prefer licensing upstream, at the level of the network access device (NAD) or the baseband processor (e.g., Schneider, 2020, p. 4).

Much of the debate on licensing level has taken a legal perspective (e.g. Kappos and Michel, 2017; Gautier and Petit, 2019; Kühnen, 2019; Dornis, 2020; Borghetti et al., 2021; Geradin, 2020), and most studies are theoretical or conceptual in nature. Some authors do mention the practical difficulties of device-level licensing for licensees and in particular SMEs (Pohlmann, 2017; Geradin, 2020, p. 17; Schneider, 2020; Borghetti et al., 2021, p. 4). Also the report by the SEPs Expert Group (2021, pp. 42, 158-159), set up by the European Commission in 2018, mentions the difficulties facing SME device makers as IoT SEP licensees.

However, there is little empirical work on the licensees' situation, in particular on SMEs and startups, despite their key role for innovation in the IoT. This paper contributes to the discussion by providing empirical evidence on IoT SEP licensing, with a focus on the perspective of startups. I draw on a qualitative study based on interviews with 18 individuals from 12 firms, totalling more than 11 hours. The sample comprises firms of different sizes, industries, countries and roles with respect to SEP licensing, including device makers, a module manufacturer, and SEP licensors. I link these findings to economic arguments regarding transaction costs, price differentiation, and industry development, and review and discuss the arguments presented in the literature.

The main result is that device-level licensing creates serious problems for device makers. Device makers have no knowledge of IoT technologies and related patents, do not know which or how many licensors could approach them, and lack an understanding of SEP licensing procedures and the concept of FRAND licensing (fair, reasonable, and non-discriminatory). This situation precludes fair licensing negotiations and invites opportunistic behaviour on the part of SEP owners. SMEs and startups additionally face resource constraints that limit their opportunities to acquire technical and legal advice, and they suffer even more from cost and legal uncertainty than large firms. Interviewees from startups perceive the current SEP licensing process as non-transparent, dysfunctional, and unfair.

The large SEP licensors in the sample, on the other hand, consider device-level licensing as the only approach allowing price differentiation, which they deem necessary in order to generate a fair return on their investments and to ensure that fees relate to the economic value of the SEPs. They also raise the issue that not all SEPs are implemented in the baseband processor, and so licensing at this level would leave some SEPs unlicensed.

Complementing the empirical study, I address three topics based on economic reasoning. Firstly, I focus on transaction costs, finding they are much higher with device-level licensing not only because of information asymmetries in the licensor-licensee dyad, but also due to the expected large number of plausibly more than 10,000 IoT device makers compared to about a dozen baseband processor manufacturers. This difference is magnified by the number of licensors. Consequences are a loss of economic efficiency and a higher likelihood of hold-up and hold-out. Secondly, I address the argument often advanced by SEP holders that royalty price differentiation is required for them to realise a fair return on their R&D investments, and would only be possible at the device level. I suggest exploring the possibility of price differentiation based on the performance of the baseband processor, and raise the question if, given the huge expected number of IoT devices and smartphones implementing cellular communication standards, even a fixed and low per-unit royalty might yield an attractive return on R&D investments. Thirdly, I discuss effects of the chosen licensing level on competition and innovation in the IoT industry.

The SEPs Expert Group (2021), along with other authors, make a number of suggestions for addressing the transaction cost problem of device-level licensing, in particular patent pools (Part 3.5), reduced or no royalties below a certain sales volume (p. 119), and an institution that could mediate FRAND licensing disputes (p. 147). I argue that these measures could partly mitigate the problems of device-level licensing but not solve them to a sufficient extent.

I conclude that device-level licensing, certainly as it is practiced now, is not feasible. It puts innovation and entrepreneurship in the IoT at risk, and would imply inconsistent licensing and hold-out. Policy makers should ensure that IoT SEP licensing is simplified in such a way that device makers can procure fully licensed IoT modules. They should commission studies on the feasibility of licensing and price differentiation higher up in the value chain, and on the aggregate cost of developing the main standards. Adding to those formulated by the SEPs Expert Group (2021, p, 182), I propose two further principles for IoT SEP licensing: licensing at a value chain level where transaction costs are minimal, and licensing in a way that promotes downstream innovation and entrepreneurship.

The remainder of this paper is structured as follows. The first part, Sections 2 to 4, presents the empirical study. In Section 2, I describe the sample and the approach of the empirical study, while Sections 3 and 4 present findings from the interviews, with a focus on the perspective of device makers and SEP licensors, respectively. The second part, Sections 5 to 7, is based on the literature and on economic considerations, addressing transaction costs, price differentiation, and industry development. Section 8 discusses potential solutions and concludes.

2. Empirical study

Between April and February 2021, I conducted 12 interviews with 18 individuals from firms of different sizes, industries, countries, and roles with respect to SEP licensing.[1] Two interviews were complemented by email exchanges. Six firms were small entrepreneurial ventures that implement mobile communication technologies in IoT devices. To capture all relevant perspectives, I also interviewed three large, established implementers, one communication module supplier, and two large SEP licensors. To indicate which quotes come from the same interview, I refer to the startups as S1 to S6; the established implementers as E1 to E3; the module supplier as M1; and the large SEP licensors as L1 and L2. Interview partners for the entrepreneurial firms were mostly founders and CTOs or CEOs. For the larger, established firms, most interviews took place with several interviewees, who were senior IP managers. Table 1 provides an overview.

Table 1: Overview of interviews

Industries:	automotive (1), diversified (1), industry automation (3), NAD manufacturer (1), security technology (1), SEP licensors (2), smart home (2), wearables (1)
Countries:	Denmark (1), Finland (1), Germany (7), Sweden (1), Switzerland (2)
Sizes:	startups founded after 2010 (6), large firms with revenues > 200 mio € (6)
Interviewees:	CEO/CTO and founder (6), senior IP manager (12)
Duration:	mean 0:58, min 00:18, max 1:31, total 11:33
Wireless standards used:	2G (1), 3G (1), LTE (5), interested in LTE (1), interested in 5G (3), Bluetooth (4), ultra-wideband (1), interested in UWB (1), Wifi (5), ZigBee (1)

Interviews lasted between 0:18 h and 1:31 h, totalling 11:33 h. They were conducted via videoconference or phone, and all but one were recorded and transcribed. In two cases [E3, L1], notes were taken in the attempt to capture important statements literally. All sources were coded and analysed using the MaxQDA 12 software package. The resulting code system has seven top-level nodes, 23 second-level nodes, 29 third-level codes, and 174 text snippets. All verbatim quotes presented have been authorised by the interviewees.

[1] Despite the wide adoption of mobile IoT technologies, it proved difficult to find startups willing to be interviewed. This reluctance is likely due to the sensitive nature of the topic: firms that had been approached by a patent holder and had been made to sign an NDA are contractually prohibited from speaking about the topic. In turn, those that had not signed an NDA, either because they had not been approached or had refused to sign, may have been aware that there are unresolved patent issues around the communication modules they procure and may thus have preferred to keep a low profile.

3. The situation of IoT device makers as SEP licensees

In the following, I discuss the actual situation of IoT device makers based on my interviews, with a focus on startups. I start with an overview of the IoT standards used, then address the characteristics of device makers that impede SEP licensing on the device level, and end with consequences for firms in terms of uncertainty and market disadvantages.

3.1. IoT standards used, suppliers, and requests for royalties

The six startups in the sample employ a variety of wireless communication standards; most of them use several standards in parallel. As shown in Table 1, LTE and Wifi are used most frequently, but 2G, 3G, Bluetooth as well as less common standards such as ultra-wideband and ZigBee are also employed.

In terms of suppliers, either direct or indirect (i.e., producing components for the modules the interviewed firms procure), the startups mentioned Avnet, Cypress, Decawave, Gemalto, Intel, Marvell, Qualcomm, Quectel, Texas Instruments, and u-blox.

Two of the six startups had been approached by SEP holders with the request to take out a licence. One of the startups had been approached by a large SEP holder (a practicing entity), a larger patent management platform, and two smaller patent-monetisation firms (or NPEs, non-practicing entities). The other had been approached by the same large SEP holder.

3.2. Lack of knowledge about IoT technologies and patents

Faced with the prospect of having to take out a licence for IoT SEPs, and in some cases an actual request to do so, startups felt incapable of assessing whether their products indeed infringed on these patents. They lack an understanding of IoT communication technologies, of the respective standards, and of applicable patents. From the interviews[2]:

> *"[…] it is for startups […] impossible to find one's way in this jungle. Because for example I completely lack transparency as to which patents the technology of a Qualcomm modem in my device actually uses." [S3]*

> *"[…] for us it would be enormously difficult to understand the thousands of patents on our module […]" [S3]*

> *"[…] how would we know all these things, I mean it's an incredibly high number of things we would have to look at proactively, when we don't even know sometimes how far we will go with one specific technology." [S6]*

> *"[…] on this module are probably three million chips and three million patents infringed. Even at TI [Texas Instruments] nobody can assess that. And we as the final device maker definitely not. So we have [number] employees, I could probably keep half of them busy with checking patents and would still not get anywhere." [S1]*

They also felt incapable of assessing the validity of patents offered for licensing:

> *"So validity of all this stuff is yet another question. We as a small firm cannot possibly check this." [S1]*

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[2] Quotes from interviews conducted in German were translated to English by the author.

An interviewee from a large, established implementer shared the startups' concerns:

> *"One cannot expect that, for instance, a manufacturer of some electrical instruments that now integrates a communication unit [into its products] informs itself about communication patents." [E1]*

Even large firms themselves face these problems, as the Association of Global Automakers and the Alliance of Automobile Manufacturers (2019, p. 5) stated in their amicus brief on the FTC proceedings against Qualcomm, Inc.:

> *"The whole benefit of vertical specialization is that a manufacturer need not worry about how the products it buys were made. But without patent exhaustion, it must worry. It must either take additional time intensively investigating components outside its area of expertise, or else take X's word about what royalties it should pay."*

An interviewee working with a large device maker [E3] addressed the specific case of licensing negotiations with a patent pool, voicing the impression that not only his/her firm as the licensee, but also the licensor were largely ignorant regarding infringement, standard essentiality, and technical merit of the patents in question. While a few technical experts were consulted, the outcome seems to have been mostly determined by the parties' relative negotiating power. Again, SMEs and startups would be in a difficult position.

An interviewee from one of the large SEP licensors stated that, to address the above issues, any licensee would have to call on external expertise. This view, however, appears unrealistic given the resource constraints of SMEs, the large number of SEP families for a single standard, the technical complexity of standards, and the effort required to assess the essentiality of even a single patent (Bekkers et al., 2020).

The interviewee further expressed the view that an implementer's claim not to know if SEPs proposed for licensing are essential, infringed, and valid would probably be an excuse to reduce royalties. My interviews with startups contradict this allegation. The concerns they expressed regarding their incapacity to assess whether IoT SEP licensing offers are plausible and appeared genuine. As a solution to the difficulty of assessing individual patents, the interviewee suggested licensees should assess the overall quality of a patent portfolio. Again, this does not appear realistic for an SME device maker, both because it lacks the required knowledge and because the quality of a portfolio needs to be evaluated relative to all patents that are essential to a standard.[3] The other large SEP licensor shared the concerns of implementers:

> *"So what should a small to medium entity do, you know, a small startup which sells for very few million or so and if they suddenly get sued by dozens of companies, by dozens of patent owners, how should they handle that, they don't have the resources. And that is a very serious concern. Absolutely." [L2]*

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[3] This principle has been laid down by the European Commission (2017, p. 8): "*In defining a FRAND value, parties need to take account of a reasonable aggregate rate for the standard.*"

3.3. Ignorance of SEPs and licensing practices

Beyond the fact that IoT standards are complex and covered by thousands of patent families, evaluating a licensing offer for a portfolio of alleged IoT SEPs also differs in other respects from licensing patents not related to such standards: each licensor's portfolio is only a fraction of all SEPs relating to the standard since SEP ownership is fragmented (see Section 5.3); royalties are typically subject to FRAND requirements; device-level licensing is uncommon in other industries; and it is important but difficult to assess whether a given patent, even if declared to be an SEP, is actually essential for the standard (Bekkers et al., 2020). These IP-related peculiarities of SEP licensing are typically not known to device makers, certainly SMEs, and thus imply additional problems for them.

Several interviewees expressed concerns about the unknown and potentially large number of SEP owners seeking royalties:

> *"€5 would not harm us, but if this is only 5 percent and then all others also demand for their share €5 then of course you get to a level where it has significant effects on the margin." [S2]*
>
> *"Yes, we would do this rather than getting into serious problems in court. Grudgingly, but relative to our size this is doable. Sure, it would be problematic if now 100 of those came and it gets around, 'go to this firm, they pay' […]" [S3]*
>
> *"[…] we cannot deal with so many patent holders. It is going to be difficult for them as well, you don't want to deal with a small company, as I said, you won't get much, so it is not worthwhile." [S6]*

One of the large SEP licensors, speaking about LTE, pointed out that only about ten SEP owners actually license their patents while all others would be dormant. While it is hard to verify how many SEP holders actually license their patents, it is clearly the case that many SEP holders do not license their patents. Still, even dealing with ten holders of SEP portfolios would be difficult for a small or medium-sized implementer. Furthermore, uncertainty remains if additional royalty demands appear.

Engaging in SEP licensing requires an understanding of FRAND principles, and all interviewees from startups showed a broad ignorance of FRAND and the process of FRAND licensing. The following quote illustrates this point:

> *"[…] in our case, I don't know how a court would decide regarding appropriateness. If this was much more than one to two Euros, then many IoT devices would not work at all. Also, I do not know the legal practice, if in the case of FRAND licensing a court can say, 'this specific patent is monopolistic and you cannot demand a royalty of €5 because then the firm XY could not build any device at all." [S3]*

The interviewee from a module supplier confirmed the licensing-related ignorance of startups:

> *"With startups, you don't have the background, the budget, and you may not even have heard about standard essential patents, unless your startup has a technical person attending meetings." [M1]*

Beyond the technical and commercial aspects, this ignorance also relates to the process of SEP licensing:

"Who has the burden of proof? Does [large SEP holder] have to prove this, or do we? I mean, anyone could come along. Or do we have to prove, no, we do not use any of your patents?" [S3]

Interviewees were also irritated by the fact that, in the case of device-level licensing, their suppliers are selling unlicensed products to them and are thus infringing patents:

"I don't know the applicable law. Can the chipmaker use other parties' patents, sell its products, and then sort of say [to its customers], 'well, if I infringe on a patent or not is for you to find out'?" [S2]

"But conversely, this means that some other firm can sell me things it has not licensed, it can make money with it, but it leaves us holding the baby, or what?" [S3]

"[…] we said, 'you know, we don't understand this, because we buy a complete chipset[4] from a wholesaler in electronics, from [supplier]. So we have the chipset from [supplier] and we said, 'you know this is strange that you are not approaching that chip manufacturer, because we buy this in good faith.'" [S5]

Some of the interviewees from startups had approached their suppliers to understand the licensing situation. One supplier said clearly that their products were unlicensed. In another case, the startup received vague answers:

Interviewer: "One question about [supplier], when they sell you that chipset, do they say anything about the licensing situation?"
Response: "No, absolutely not. Well what we did do though was, we went back to understand how this could be our problem, right. So we talked to [distributor], who was the distributor of this [supplier] chip and they said: 'Hey, this has nothing to do with us and we are just selling that [supplier] chip.' And then we went to [supplier] […] I think it actually escalated, but he came back and said: 'We don't have any violations, we don't have any agreements.' […] So we followed the chain back but none of them felt it was their problem." [S5]

3.4. Resource constraints

The above problems—a lack of knowledge regarding IoT technologies and patents as well as SEPs and licensing practices—affect IoT device makers of any size. For startups and SMEs, however, they are compounded by the resource constraints that come with small and medium size. A startup or SME cannot afford the cost of technical and legal expertise required to assess a list of patents for infringement or standard-essentiality, even less litigation. Several interviewees stated this concern:

"Actually, no SME can afford that." [S1]

"[…] we asked them actually to detail exactly how—so one of our replies to them was, can you tell us specifically which one and they said here is a list of all our patents and we said we are a small company, we don't have a lawyer who can tell us which one [we infringe]" [S5]

"I guess even if I would have the world to do that, I wouldn't even know how to do it, right? Because it would only add complexity and cost and probably not really be a solution and I could still be approached by someone who claims to have a fraction of the method

4 The term "chipset" is by and large synonymous with "baseband processor", and in this article is used in this sense. While historically, a chipset was an actual set of several chips (e.g., https://en.wikipedia.org/wiki/Chipset), the various elements of a chipset are now typically integrated into the processor.

> *further down the line, right? So I would only delay my own innovation of the time to market and add a lot of cost I cannot afford to pay." [S5]*

> *"[…] for a startup, it's a substantial expense to get educated, because they'll have to reach out for expertise. […] It's a cost that you didn't plan for. It's also a liability that your financer may not appreciate […]" [M1]*

> *"So what shall a small medium entity do […] how should they handle that, they don't have the resources. And that is a very serious concern. Absolutely." [L2]*

Adding to the above resource constraints, SMEs also lack management capacity. Relative to the size of the firm, licensing negotiations regarding technologies they do not understand would put a high burden on the management and distract it from its main tasks—to innovate, find customers, and grow the firm.

3.5. Uncertainty and market disadvantages

The issues described above create uncertainty for implementers, regarding cost and legal issues. Since during the development of a new IoT product, it is not clear which demands for SEP royalties will come up later, innovators cannot make reliable cost calculations. While they could add an extra margin to provide for potential royalty requests down the road, doing so would put them at a disadvantage vis-à-vis competitors that are less cautious. Interviewees' statements reflect these concerns:

> *"[…] right now it is certainly a problem because there are no rules and we cannot solve this problem in advance, but are as a small buyer in the end at the mercy of the patent owners. So we cannot fully invest in the technology today, without considering this and asking, 'okay, what is the risk that we take and how much do we have to pay in the end for individual devices and how can we pass it on to the customer'. We have no financial control whatsoever." [S4]*

> *"[…] if I make an agreement today I am signing with any kind of partner downstream. I'm signing an agreement that if I'm selling a product that is violating a patent […] it's on me right to cover the cost. In this case, I can apparently go to a huge chip manufacturer, buy a chip set and then further down the line be approached by [large SEP holder]. Because apparently, it's easier to go for the smaller companies then make a deal with a bigger one." [S5]*

Financial uncertainty due to unclear licensing obligations may also create problems with actual and potential investors:

> *"[Faced with a lawsuit] [t]hey'll panic and their investors will get nervous and it just doesn't go as well for a true startup where you got 5 to 10 people or even up to 100 are trying to make something work." [M1]*

Related to cost uncertainty is the problem that, in the end, actual cost will differ between competing device makers, depending on which were approached by SEP holders and which actually took out a licence. Such unequal licensing treatment penalises implementers that are more prudent or more willing to pay:

> *"[…] at the end of the day it stacks up and my cost for the device has been increased because I pay that licence and someone else did not. And that's a competitive disadvantage." [S5]*

> *"I think what will happen is that they will try this with 100 companies and maybe 20 will respond and one of the ones which responds, they will try to get something out of them." [S6]*

In the same vein, one of the large SEP holders interviewed conceded that they are unable to ensure equal licensing of all smaller firms that use their technology.

One interviewee from a startup pointed out that in addition to risks related to cost uncertainties, the legal uncertainties of patent infringement carry their own risks:

> *"[…] the normal person, without legal training, would probably panic, because patent law has all sorts of cruelties that can hit an individual personally. […] in principle, as the head of development or possibly as the CEO you can find yourself in the dock […]" [S1]*

Cost and legal uncertainty are aspects of the broader problem, attested by interviewees from startups, that there is no coherent regulatory framework for SEP licensing:

> *"[…] for me we are still in the machinery trying to get the patent holders to define some rules, because right now it's anarchy. It seems like anarchy." [S5]*
>
> *"[…] to some extent I present that outside view […] from someone who gets dragged into this and when you look at it as a newcomer, it just seems super dysfunctional and not sustainable." [S5]*

3.6. A process perceived as unfair and unsustainable

Interviewees from startups, and also most other interviewees, expressed the view that the current process of IoT SEP licensing—if it can be called a well-defined "process" at all—is unfair and unsustainable, certainly for small and medium-sized implementers. This view relates to implementer traits, to the process itself, and to the potential outcomes.

Regarding firm characteristics, one interviewee pointed to SMEs' lack of negotiating power :

> *"[…] we as a small buyer have no hold over the licensors. If one has a larger volume, then of course one has many more possibilities. For Tesla there would be other possibilities […] in the end we're speaking about [number] devices maximum, in that case one has no leverage over these firms, they are in the driver's seat." [S4]*

Also on the political level, SMEs are seen to be disadvantaged due to their relative lack of lobbying power:

> *"[…] one of the things about SMEs I have heard for years […]: 'We want to hear from the small and medium sized companies. We want your opinion, we want to know.' But I'll tell you what I've found while working with SMEs. The opposite is true. Most companies don't want to hear from SMEs. It's the Apples and Googles of the world, and Nokias of the world that control the conversation. And when you hear from an SME, you're gonna hear something very different, which tends to be suppressed, because SMEs don't have the budget to lobby, they don't have the budget to attend every policy meeting." [M1]*

The licensing process itself is seen as problematic for various reasons, several of which have already been addressed above. One particularly difficult point is that SEP owners approaching an implementer for royalties would typically, as a first step, ask the potential licensee to sign an NDA (non-disclosure agreement). While this may be normal business practice when parties negotiate on equal terms, signing an NDA would deprive the potential licensee of the chance to collect much-needed information from peers and even suppliers:

> *"For instance, I am completely lacking transparency about which patents the technology of a Qualcomm modem in my devices actually uses. And under an NDA I might not even get this [information]." [S3]*

> *"So they asked us to sign an NDA and then we talked to our lawyer and he said, 'You know what, you cannot really sign that because then you cannot go and speak with [distributor] and [supplier] and you cannot talk to others that may be in the same position', right. And because we wanted to do that, I mean, if we had signed that claim we would have been done, right? Because then we would only have been able to let's say communicate with [potential licensor] on their terms for this discussion. And so we wanted to say, you know we need to be able to talk to others than our lawyers about this." [S5]*

The startups in my sample that were approached by potential licensors were indeed requested to sign NDAs. They refused to do so—without dire consequences. Still, other implementers may feel they need to sign, in particular if the licensor exerts more pressure, and the request alone may put a firm into an awkward situation.

One interviewee perceived the entire process as unfair, as "bullying":

> *"We really felt like we are just being cornered and bullied by a big player here, right. I mean we felt completely outmaneuvered, we didn't have money for lawyers, we didn't have insights, this was not a fair game. The process was not a fair game, so even if they had a legitimate claim, all right, and they are frank, have principles and all this, just by approaching us, a small startup, for me it is unfair." [S5]*

One should note that the interviewee does not deny that the potential licensor may have had a legitimate claim. In fact, all interviewees acknowledged that owners of IoT SEPs should receive fair royalties for the use of the respective standard. Their critique mostly related to the process, which makes it impossible for them to assess a licensing offer and determine if it is fair. In one case, though, an interviewee explicitly addressed the amount of royalties requested:

> *"And one more thing that I really find surprising, this is what people consider a [appropriate] royalty. What is considered 'normal' is quite high. […] if everyone who somehow owns such a patent comes along there will be nothing left of the dough [profit margin], it becomes negative." [S1]*

Interviewees also pointed beyond their own situation, complaining that not only IoT SEP owners but owners of patents on other inputs may start engaging in device-level licensing. This situation would border on the absurd:

> *"We don't just have communication chips on the device. For example, we also have [type of sensor]. Who knows what kind of measurement methods or whatever other patents there are. I think if we started with all sensors and chips on our device this would become infinitely complex, and would not be commensurate with our size." [S3]*

> *"It will not work this way. This is also the issue that we have in the automotive industry, that we build a car from many thousands of components, and of course we cannot have the knowledge about each technology in-house, this would be insane." [E1]*

One should note that, for the two startups that were approached for SEP royalties, none of the requests led to an actual licensing contract. The startups argued to the potential licensors that they had no understanding of the respective technology, that their suppliers would be more appropriate licensees, and that their revenues were still too small to make licensing worthwhile. After more or less lengthy exchanges, the respective SEP holder abandoned its licensing attempts, without indicating its reasons for doing so. The startups were relieved to have fended off the challenge, but felt uncertain if, when, and from whom further licensing requests might come.

3.7. Summary

The situation of IoT device makers as SEP licensees is difficult. It is characterised by, (a) a lack of knowledge regarding IoT technologies and related patents; (b) ignorance of SEP licensing practices, the set of potential licensors, and the finer points of SEPs and FRAND; (c) for small and medium-sized firms, resource constraints that limit the possibilities of acquiring technical and legal advice; (d) cost and legal uncertainty; (e) and an SEP licensing process that they perceive as non-transparent, dysfunctional, and unfair, putting them at a disadvantage vis-à-vis licensors. The licensing relationship is characterised by high transaction costs due to information asymmetry.

4. The perspective of SEP licensors

Two interviews, totalling 2:31 h and comprising six interviewees, were conducted with large SEP holders that are practising entities. Some quotes from these interviews that refer to the situation of IoT device makers as SEP licensors have already been presented in Section 3. Most quotes, however, refer to the licensing level in the value chain. They are presented and discussed in the following.

4.1. Price differentiation and licensing level

Interviewees from both firms considered it important to differentiate price depending on the use of the respective IoT technology. One interviewee explained the negative consequences that, in his/her view, a fixed per-unit royalty, independent of the use case, would have:

> *"Or should it be nonetheless flat across the board? So one price, one technology. And I think that if you – in the field of cellular, where there is a significant fluctuation potentially between those values – would apply a flat rate nonetheless, […] one of two things would happen. First, the price would actually get scaled down to the lowest value so that everybody could afford it. And that would actually mean that the incentive for the contributors to continue contributing would go down significantly, because they wouldn't be receiving the fair compensation […]" [L2]*

The views echo the standard economic argument regarding price differentiation, which I review in Section 6.1. Interviewees from both large SEP licensors expressed the view that effective price differentiation cannot be achieved with licensing higher up in the value chain (in particular, at the chipset level), which means it needs to take place at the device level.

> *"Going any higher in the supply chain, we run into the same problems that there's just no way to track the end product of a module or of a chipset. And that results to all these challenges that we've been discussing already in this call, how to value, how to price, how to track down, how do we make sure that, how do we as a licensor know which products are licensed in the market other than by just buying these products and ripping them out and still it would be just this product that we open up and see what is in the module that we are looking at?" [L2]*

> *"[…] it's difficult or practically impossible to know, at the chipset level, what use that particular chipset will be put into, so we don't know how much to charge because we don't know what it is going to be used for." [L2]*

> *"And [the device level] is the best place to basically take into account the value of the technology that is incorporated into a product." [L2]*

The implicit assumption in these statements is that price differentiation needs to be tied to the final use of the standardised technology, and thus to the device in which it is integrated. However, it may also be possible to tie it to the quality and performance of the standard implementation in the baseband processor, an option I discuss in Section 6.3.

The practical implementation of price differentiation may entail high transaction cost in order to categorise potential buyers by their willingness to pay (WTP). In the case of IoT SEP licensing, these transaction costs are considerable, as reflected in Section 3 and further discussed in Section 5 below.

An interviewee from a module manufacturer noted a shift in SEP holders' licensing strategy to device-level licensing. He explicitly made the point that, in targeting the device level, the licensors' goal was to increase royalty income:

> *"[…] the idea behind the ETSI [European Telecommunications Standards Institute] policy was that, an individual or a company that wanted to have access to the technology, you would give them access. The Nokias in the world have now interpreted that, and I can tell you, this is a big change. They now interpret it as of – four years ago when they had a change in their business, four or five years ago. They went from 'I will talk to anyone in licensing' to 'will only talk to end product manufacturers.' They are trying to maximize revenues. And they needed to because the company was in financial problems." [M1]*

4.2. Implementation level of SEPs

In addition to price differentiation, interviewees from SEP licensors also explained the choice of licensing level by patent-related arguments. They raised the point that IoT SEPs may be implemented at various levels of the value chain, such that licensing at the chipset-level may leave some SEPs unlicensed:

> *"[…] many of the [firm name] patents claim, for example, user equipment that are devices that are intended to be used by an end user. So it's not sure that the chipset even infringes on those patents, and if we licensed the chipset, then those patents do not get licensed, nor do they get exhausted by the patent exhaustion doctrine. Which means that, in the end, if a company uses that chipset, even if it were licensed, there are still a fair number of patents for which the licence doesn't pass through to them. And we have to make another licence agreement with them in any case […]" [L2]*

> *"[…] we have a number of patents for example, which require also the interaction of the chipset with the user interface, with the antenna, with other things. And on top of that, of course, most of the patents also have process claims and the process claims are never implemented in a TCU, just because the process claims require that the data stream is generated, is transmitting information and so on. And this all of course, only happens once the TCU is implemented in the car." [L2]*

One statement even claimed that some IoT SEPs are only infringed by the car, not by any other value chain level above:

"[…] telematics control unit does not infringe all of the patents that [firm name] has in its SEP portfolio, and that those patents are only infringed by the car, which means that there would have to be a separate licence for the car, in any case for the remainder of those patents." [L2]

While these arguments are plausible from a legal perspective, their practical relevance appears questionable. Even if an SEP requires the interaction of the chipset with a part of the car, it most likely does not imply that the patented invention requires actual changes to that part; rather, it is likely a matter of how the patent is drafted. The same applies to the argument that the chipset could not fully implement process claims. These points will be discussed in more detail in Section 5.4.

4.3. Summary

The interviewees from large SEP holders stated two main reasons as to why their firms prefer device-level licensing. Firstly, because it facilitates price differentiation based on the use of the IoT technology, which interviewees considered necessary in order to generate a fair return on their R&D expenditures while also serving the low end of the market. Secondly, they stated that some SEPs are not only, or even not at all, realised in the chipset, such that chipset-level licensing would leave them unlicensed.

5. Transaction costs

Reducing transaction costs increases the efficiency of a market and is desirable from a societal perspective. It is also a declared goal of the EU Commission (2017, p. 7) in the context of SEP licensing: "*Transaction costs relating to the negotiation of a licence should be kept to the minimum necessary*." In the following, I address five aspects of transaction costs: transaction costs of an individual licensing relationship; the number of licensees; the number of licensors; the issue of multi-level licensing; and the resulting problems of hold-up and hold-out.

5.1. Transaction costs between licensor and licensee

The situation of IoT device makers as SEP licensors depicted in Section 3 provides evidence of high transaction costs within the dyad of licensee and licensor. These transaction costs are due to uncertainty, a lack of competence on the part of the licensee, asymmetric information, and the resulting risk of opportunistic behaviour. These problems are acknowledged by various authors (Pohlmann, 2017; Geradin, 2020, p. 17; Schneider, 2020; Borghetti et al., 2021, p. 4). Milgrom and Roberts (1992, p. 29) refer to such transaction costs as "motivation costs." Their existence hinders transactions and may prevent them altogether. Licence negotiations on equal terms with regard to technical and SEP-related competence can only be expected between SEP owners and baseband processor manufacturers.

In addition to motivation costs, a second type of transaction cost between licensor and licensee also matters when choosing the licensing level. Milgrom and Roberts (1992, p. 29-30) refer to them as "coordination costs," associated with identifying licensees, negotiating, and monitoring contracts. Just as with motivation costs, they make transactions slower and more difficult, or even impossible if, e.g. a licensee is difficult to identify. Their dependence on firm size, and thus, indirectly, the licensing level, is ambiguous. A large prospective licensee will in general be easier to identify than a small one, and probably more professional in negotiating and monitoring; on the other hand, negotiations with a large licensee will likely be more complex.

In sum, dyad-level transaction costs are grounds for licensing higher up in the value chain.

5.2. The number of licensees

Both types of transaction costs, motivation and coordination costs, grow with the number of potential licensees since this directly affects the frequency of licensing transactions.

Even casual observation shows that industry concentration decreases steeply from baseband processor makers to device firms. Regarding baseband processors for cellular communication technologies (3G, 4G, 5G), current market studies address five respectively six manufacturers explicitly: Qualcomm, MediaTek, Intel, Broadcom, Spreadtrum, and ST-Ericsson.[5] Further industry players are HiSilicon, Icera, Marvell Technology Group, and Samsung LSI. While this list may not be comprehensive, it is safe to describe this industry as highly concentrated; a recent industry study put the market share of the top three firms in 2019 at 71 percent.[6]

At the other end of the value chain, the market for IoT devices using mobile communication technology is highly fragmented (see also SEPs Expert Group, 2021, p. 41-42). In fact, it is not a single market at all but multiple markets, since mobile IoT products and application areas are as diverse as cars, industrial machines, smart home appliances, farming, wearable devices, retailing, health, sensors, and tracking wild animals.[7] An exact estimate of the number of firms making IoT devices is difficult to obtain. It is certain, though, that this number will be large, likely five-digit globally, and that it is growing strongly.[8]

The market for NADs will likely be between that for baseband processors and that for mobile IoT devices in terms of its fragmentation; given the relatively low degree of differentiation compared to devices, it should still be relatively concentrated.

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5 https://www.decisiondatabases.com/ip/38054-baseband-processor-market-analysis-report and http://www.marketsnresearch.com/global-baseband-processor-market-status-by-manufacturers-types.html.

6 https://news.strategyanalytics.com/press-releases/press-release-details/2020/Strategy-Analytics-2019-Cellular-Baseband-Market-Share-5G-Basebands-Capture-2-Percent-Unit-Share/default.aspx.

7 See, e.g., https://iot-analytics.com/10-internet-of-things-applications/ and https://iot-analytics.com/top-10-iot-segments-2018-real-iot-projects/.

8 Wifi or WLAN technology based on the IEEE 802.11 family of standards is also a key technology for the mobile IoT. The situation regarding the relative number of firms on the various levels of the value chain is qualitatively the same as for cellular technologies, with relatively few chipmakers and a large number of device makers—probably even more than for cellular technologies owing to the lower cost and complexity of Wifi compared to cellular technologies.

The transaction costs incumbent on royalty-bearing licensing agreements increase with the number of licensees. Thus, even if a licensing contract with a device maker will likely be simpler than one with a baseband processor maker, the strong increase in the number of potential licensees when moving from the level of the baseband processor to that of the final device entails a strong increase in transaction costs (see also Pentheroudakis and Baron, 2017, p. 29). With ten baseband processor manufacturers and 10,000 device makers, a thousand times as many licensing contracts will have to be closed when licensing at the device level compared to licensing at the processor level. It will hardly be possible to do this consistently, which implies an uneven playing field for device makers and lost royalty income for licensors.

A countervailing argument, again related to transaction costs, is that reliable information on the number of units produced may be more difficult to obtain upstream than downstream. Teece and Sherry (2016, p. 2), for instance, argue that "*transaction cost considerations make SSPPU licenses difficult to monitor and enforce*." Whether this argument is valid is difficult to assess. The companies mentioned in the studies of the baseband processor market cited above in Footnote 5 (Qualcomm, MediaTek, Intel, Broadcom, Spreadtrum, ST-Ericsson) are well-established and reputable firms; one should expect them to report correctly. In fact, it may well be that monitoring small firms is more difficult due to their limited general reporting obligations and less formal structure, even ignoring the fact that they are much more numerous. In case of licensing at the NAD level, a forgery-proof version of the (device-level) International Mobile Equipment Identity (IMEI) number could possibly be used to check if a given device is licensed.

In conclusion, considering how the number of licensees affects overall transaction costs inclines to licensing upstream, at the level of the chipset or the NAD.

5.3. The number of licensors and the promise of patent pools

The number of licensors also affects the transaction costs of licensing. While the number of licensors should be independent of the licensing level, the absolute increase in transaction costs that comes with an increase in the number of licensees is higher the more licensors there are. By way of illustration, with ten baseband processor makers, 10,000 device makers, and N licensors, the number of licensing relationships increases by 9,990 N , from 10 N to 10,000 N, when moving from the processor to the device level. Thus, the number N of licensors does matter in choosing the optimal licensing level: The more licensors there are, the more important it becomes to keep the number of licensees low.

How many licensors are there for cellular IoT technology? A recent study by IPlytics (2019) found, as of November 2019, 22,604 patent families declared as essential for 5G. The top 32 declaring organisations account for 19,808 of those, or 87.6%. The remaining 2,794 are accounted for by organisations with 11 or fewer declared patent families each, yielding a likely number of more than 500 SEP holders.[9,10] Numbers for 3G and 4G are lower, but still three-digit. Overall, the number of contributors to cellular standards has increased strongly over time, driven also by the increased complexity of the IoT (5G) compared to earlier standards (SEPs Expert Group, 2021, pp. 36, 41-42).

Of course, not every single SEP holder will seek royalties, and a share of those that do will band together to license their patents through pools. Patent pools offer a way to simplify licensing if patent ownership is fragmented. For IoT standards, Avanci is a prominent pool, listing as of March 2021 41 licensors of 2G, 3G, and 4G SEPs on its website.[11] Diakun (2019) finds that Avanci "*covers just under 50% of 3G and 4G SEPs*", while Noble and Vary (2020), applying a number of filters and corrections, found shares of around 75% for 3G and 65% for 4G. This is a remarkable achievement for Avanci, but still far from offering one-stop shopping. Licensees may still have to deal with two-digit numbers of licensors. If the current list of Avanci's licensors gives any indication for a future 5G patent pool, one needs to note that only 17 of Avanci's licensors are listed among the top 32 organisations in terms of patent families declared essential for 5G (IPlytics 2019). Notably, the three firms with the largest numbers of 5G SEP declarations—Huawei, Samsung, and LG—are missing from Avanci's list, and the number of licensors falls far short of the estimated number of more than 500 owners of 5G essential patent families.[12] Thus, Avanci mitigates the problem of fragmented patent ownership, but does not solve it.

In addition, the practice of some large SEP holders, notably Ericsson and Nokia, of transferring parts of their SEP portfolios to patent monetisation entities works to *increase* the number of individual

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9 The numbers of declared patent families are shown in Table 1 in IPlytics (2019). The table lists the "Top patent owners of 5G declarations", and the firm in the list with the smallest number of declared patent families, Spreadtrum Communications, features 11. Thus, the declaring organisations not on the list should each have declared 11 patent families or fewer. If each of those had exactly 11, the number of declaring organisations not on the list would equal 254. However, given the typical characteristics of long tails of distributions (e.g., https://en.wikipedia.org/wiki/Long_tail), in particular convexity, the average number of declared patent families per declaring organisation will likely be below 11/2 for those declaring organisations that are not on the list, yielding a number above 500.

10 Not every patent family declared to be essential is factually essential. Still, it is unlikely that all declared SEPs in a given portfolio are inessential. Thus, the number of holders of patent families factually essential for 5G will hardly be lower than the number of holders of patent families declared to be essential for 5G. Furthermore, it requires considerable effort to actually show whether a given patent family is essential for a standard or not.

11 As of March 21, 2021. https://www.avanci.com/marketplace/#li-licensors.

12 One should note that the 39 SEP holders listed on Avanci's website comprise patent licensing firms that did not themselves declare SEPs to the respective standard setting organisation and thus are not counted among the estimated 500 individual SEP owners (see footnote 9).

licensors, and thus counteracts the potential positive effect of patent pools.[13] And even if Avanci attracts more licensors in the future, it is unlikely ever to cover most cellular IoT SEP holders. This is, firstly, because of the sheer number and heterogeneity of patent holders. Secondly, it is due to a problem inherent in patent pools: regarding revenues, a single SEP owner typically fares better by charging royalties separately than by joining the pool. The underlying economic problem is one of excessive pricing of complements (here: licences from the various SEP holders), as pointed out already by Cournot (1838). Thus, joining a patent pool is attractive only for those SEP holders for whom the concomitant transaction cost advantage outweighs the loss in revenue. It is unlikely that this will be the case for all SEP holders or even a majority of them (see Pentheroudakis and Baron, 2017, p. 169 and references therein). Consistent with this argument is that Huawei, Samsung, and LG, according to their declarations the owners of the largest 5G SEP portfolios, have not joined Avanci. While the European Commission appears to see voluntary patent pools as a potential solution[14], they are unlikely to be effective.

In conclusion, the number of individual SEP licensors will easily be two-digit. Assuming only 10 individual licensors and 10,000 mobile IoT device makers yields a number of licensing contracts of 100,000 with device-level licensing, compared to 100 licensing contracts if baseband processor makers were licensed. Thus, the presumably large number of individual SEP licensors is also grounds for licensing high up on the value chain where industry concentration is high.

5.4. Multi-level licensing

Not all SEPs are realised in the baseband processor, or at least not in the baseband processor alone (this issue had also been raised by interviewees, see Section 4.2). Putnam and Williams (2016) report for a sample of SEPs from Ericsson that 71% of the 122 examined patents were realised in the baseband processor, but all of them also referred to other components. This appears unusual, though. Vary and Warne (2020) even claim that "*[f]ew patents are actually implemented in the chip*", which appears implausible. In contrast, Continental and Denso (2019, p. 19), suppliers of telematics control units (TCU, modules that contain an NAD), state in an amicus brief for the Federal Trade Commission's legal action against Qualcomm, Inc.: "*Most, if not all, of the technology protected by SEPs is practiced*

[13] For instance, in 2013 Ericsson transferred more than 2,000 patents to Unwired Planet (e.g., https://www.forbes.com/sites/ericsavitz/2013/01/14/litigation-ahead-unwired-planet-buys-2185-ericsson-patents/), and Nokia sold a portfolio of more than 500 patents and patent applications to Sisvel in 2011 (https://www.sisvel.com/licensing-programs/wireless-communications/wireless/introduction). Somewhat ironically, both Unwired Planet and Sisvel are listed as licensors on the Avanci website, so Avanci re-aggregates portfolios that the original owners had intentionally disaggregated.

[14] See European Commission (2017, p. 8): "*The Commission calls on SDOs and SEP holders to develop effective solutions to facilitate the licensing of a large number of implementers in the IoT environment (especially SMEs), via patent pools or other licensing platforms, while offering sufficient transparency and predictability.*"

at the most upstream point in the supply chain—the level of the chips." A broader, more representative, and neutral technical study is required to assess this question.

Furthermore, if an SEP is realised both in the baseband processor and some other component needed to realise the respective communication function, it would be sufficient—and would not create any distortion of competition—to charge royalties to the processor maker while granting a free licence to the maker of the complementary component. And if the complementary component is merely mentioned in the patent, but not actually affected by the patented invention (as is likely the case for the user interface or the antenna mentioned in the interviews, see Section 4.2), then there is no economic nor technical reason why the maker of that component would require a licence.

In any case, the possibility that not all SEPs are realised in the baseband processor alone need not be an argument against licensing at the *NAD* level, since all (terminal-side) SEPs should be implemented there. The term "smallest saleable *standard*-practicing unit" or SSSPU would be appropriate here, in contrast to the SSPPU ("smallest saleable patent-practicing unit"), which can be different for different SEPs. In the end, where exactly IoT SEPs are implemented is a technical question, and should therefore be addressed by technical experts.

5.5. Hold-up and hold-out

The transaction costs involved in SEP licensing may give rise both to hold-up and hold-out. Kühn et al. (2013, p. 3) state that "*[h]old-up occurs when the SEP owner approaches firms practicing the standard—after those firms have invested in developing their products that depend on the standard—with an onerous licensing demand.*" The widespread ignorance of device makers regarding SEP licensing obligations, relevant patents, potential licensors, and appropriate royalties (see Sections 3.2 and 3.3), possibly compounded by an NDA forced upon them by the licensor, suggests that they could more easily end up in a lock-in situation than upstream firms, and that opportunistic licensors may demand supra-FRAND royalties. These considerations are grounds for licensing higher up in the value chain.

Hold-out, in contrast, "*refers to an unwilling licensee of an SEP seeking to avoid a license based on the value that the technological advance contributed to the prior art*" (Pentheroudakis and Baron, 2017, p. 113). The startups in my sample that had been approached by potential SEP licensors had argued that their suppliers would be the appropriate licensees and had, in the end, not taken out any licence. This may be because the respective SEP owner followed the implementer's reasoning or because the startups' production volumes were still too low to make licensing worthwhile. It does, however, show the potential for hold-out: the high transaction costs of licensing SEPs to potentially tens of thousands of mostly small firms creates high transaction costs that quickly render a licensing effort unprofitable if the implementer is unwilling. This is consistent with Heiden and Petit's (2017, p. 180) finding, based on a survey of 12 SEP licensing executives, that "*small- to medium-sized enterprises ('SMEs') […] seek to avoid payment altogether.*" While they find that also multinational corporations operating in developed markets engage in patent hold-out (or patent trespass, as they term it) "*with the* *main goal of reducing their royalty payments*" (p. 179), the challenges involved in licensing to SMEs and in particular the possibility of patent hold-out speak for licensing higher up in the value chain.

6. Price differentiation

6.1. Advantages and downsides of price differentiation

The views expressed by interviewees from SEP licensors (Section 4.1) echo the standard economic argument that price differentiation, in principle at least, allows a seller to achieve two goals: firstly, price differentiation makes it possible to serve all potential buyers with a WTP above the supplier's marginal cost, by charging a low price to buyers with a low WTP. Secondly, it allows capturing a larger absolute share of the higher WTP of the high-end buyers by charging them a higher price.

The downsides of price differentiation are that its enforcement is typically costly, requiring separation of buyer groups and preventing arbitrage between them. If indeed device-level licensing was required to facilitate price differentiation, then the resulting increase in transaction costs would be the cost of enforcing price differentiation. Furthermore, price differentiation requires market power, and FRAND obligations restrict market power. Thus, it is not obvious which kinds of price differentiation are consistent with FRAND obligations and which are not.

6.2. The contribution of a standard to end-product value

Price differentiation exploits differences in buyers' WTP. Arguably, manufacturers of expensive devices such as cars should find it easier than makers of lower priced devices to pass on a cost increase due to IoT SEP royalties to their customers. As a result, their WTP for IoT SEP licences should be higher. However, a FRAND royalty should not be linked to the licensee's WTP per se, but rather to the value contribution that the respective standard makes to the device—and the value contribution of a mobile communication standard to a device costing €100,000 may well be less than that to a €100 feature phone. The challenge is how to determine this value contribution.

Basing royalties on the price or type of the end product is economically justified only to the extent that a higher price is due to higher synergies of the product's other components with the component implementing the standard. Otherwise, a dependency on the product price rewards the licensor for value-adding features of the end product that are unrelated to the standardised technology. In the case of mobile phones, for example, it appears neither fair nor appropriate for an SEP holder to demand higher licence fees because the device contains a brighter screen or a higher-resolution camera (see also Geradin 2020, p. 17). In contrast, it is appropriate to charge higher royalties for baseband processors of higher performance—and since more expensive mobile telephones usually contain better processors, the use of the device price as the basis for calculating royalties can at least on average be justified. However, this is a coincidence. There is no economic justification for tying royalties to the price of a product if this price is driven by other components.

This view is in line with the position of the European Commission (2017, p. 8, underline added): "*Determining a FRAND value should require taking into account the present value added of the patented technology. That value should be irrespective of the market success of the product which is unrelated to the value of the patented technology*." Related, in a commentary on the FTC's proceedings against Qualcomm, Inc., Muris (2019), professor of law and former chairman of the FTC, writes: "*[C]onsumers pay for improved displays, storage, or facial recognition; yet Qualcomm's royalty terms capture 5 percent of that increased value, which has nothing to do with Qualcomm's patents*." Müller (2021) takes a similar position.

Thus, the argument that licensing at the end product level would allow clear identification of the value contribution of the standard in question does not appear conclusive. In fact, it becomes extremely difficult to tease out the value contribution of a given technology to a complex product consisting of a multitude of elements. It would seem more appropriate to consider the performance of the standard implementation, for instance, its bandwidth and latency (see Section 6.3)—and those characteristics are related to the chipset, not to the device.

6.3. Royalties based on the quality of the standard implementation

Interviewees from SEP licensors found price differentiation indispensable, and considered it impossible to do on the level of the chipset (Section 4.1). This assumption, however, requires checking since different baseband processors implementing the same standard can differ considerably in performance and, related to this, price. Such differences should be a suitable basis for price differentiation.

Indeed, there is performance variation between IoT modules. The company u-blox, for instance, offers cellular modules implementing LTE-M, LTE Cat 1, and LTE Cat 4+, with data rates in the kb/s range, 10 Mb/s, and 150 Mb/s, respectively.[15] Telit offers a similar range of differentiated products.[16]

Differences in the performance of baseband processors and, related to this, in price, offer licensors well-defined criteria for charging higher royalties where the standardised technology provides a higher benefit. Such price differentiation would be in line with Article 289 of the Guidelines on the Applicability of Article 101 TFEU, which demand that "*the fees bear a reasonable relationship to the economic value of the IPR [intellectual property right]*." While arguably the same processor can create different value depending on the device in which it is implemented, charging royalties based on the processor's characteristics would capture the value of the IPR better than charging royalties based on the device while ignoring the performance of the standard implementation.

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[15] See https://www.u-blox.com/sites/default/files/CEL-product_Overview_%28UBX-14001802%29.pdf.

[16] See https://www.telit.com/m2m-iot-products/iot-module-selector/.

Consistent with the above considerations, the SEPs Expert Group (2021, Section 6.2.4) proposes that, if connectivity rates differ between applications, "*SEP holders could license their SEPs at chip-maker level and charge different royalties for the different chips depending on the connectivity rates of these chips*."

In conclusion, price differentiation based on the characteristics of the baseband processor and thus the performance of the standard implementation appears both doable and in line with FRAND requirements.

6.4. The SSPPU as the royalty base

Related to the question of price differentiation is the discussion around the "smallest saleable patent-practicing unit" (SSPPU), typically understood to be the baseband processor. Several U.S. court decisions have used the SSPPU as the royalty base (e.g., Vary and Warne, 2020). The argument is that with complex products determining royalties for patents relating to a single component, considering the entire product is challenging (see Section 6.2). Furthermore, if the value of the final product is used as the royalty base (the "entire market value", EMV) there is a risk that the patent holder will be rewarded for features of the product that are unrelated to the patented technology.

In turn, the SSPPU approach has been criticised on the grounds that it fails to properly account for synergies between complementary components and for the contribution of the patented technology to the value of the final product (Sidak, 2014; Petit, 2016; Putnam and Williams, 2016; Teece and Sherry, 2016; Kappos and Michel, 2017; Gautier and Petit, 2019), and several court decisions have rejected it (e.g., Vary and Warne, 2020).

However, there are more options than EMV and SSPPU (e.g., Layne-Farrar, 2017). Importantly, two aspects of SSPPU licensing have sometimes been commingled that should be separated: how to calculate royalties, and where to charge them. Regarding the calculation of royalties, SSPPU licensing typically means using the value of the SSPPU as the royalty base (e.g., Heiden, 2020, p. 7). This approach to royalty calculation is problematic unless the royalty rate has been adjusted to the royalty base (e.g., Teece and Sherry, 2016, p. 2; Kühnen, 2019, p. 970). In keeping with these arguments, the SEPs Expert Group (2021, p. 84) suggested the "*principle of neutrality*", implying that the "*value of a SEP licence should not depend on the level in the value chain where the licence is taken.*"

Adjusting the royalty rate to the royalty base can address the criticism cited above. Doing so may lead to high royalty rates if the price of the SSPPU is low, which according to Gautier and Petit (2019, p. 691) *"may […] lead some courts and juries to consider that high nominal royalty rates are 'big,' possibly prohibitive, while low nominal rates are more likely to look fair.'"* This argument, however, does not appear convincing in the long run. To draw an analogy, the share of the selling price of a movie DVD attributable to royalties for the content is typically considerably larger than the share attributable to the production cost of the disk. Thus, while the comparatively low price of an SSPPU inclines against using it as the royalty base with an unadjusted royalty rate, it does not argue against charging royalties on the value chain level of the SSPPU producer if the royalty rate is suitably adjusted. In the case of cellular technology this is the manufacturer of the baseband processor or possibly of the NAD.

Thus, the arguments against SSPPU licensing cited above can be reconciled with licensing at the level of the baseband processor.

7. Industry development

The choice of where to license IoT SEPs also has consequences for industry development, both for upstream competition and for innovation and entrepreneurship.

7.1. Additional transaction costs from "access to all"

In order to minimise transaction costs, royalties should be charged at one level only, as charging them at two or more levels would lead to a duplication of transaction costs and, in addition, the possibility of excessive royalties ("double dipping") facilitated by a lack of transparency. In this regard, there is general agreement (e.g., SEPs Expert Group, 2021, pp. 11, 84). The question remains how the other levels should obtain the right to practice the SEPs in question. Should any level be entitled to request an explicit licence, an approach labelled by some authors "licence to all" or "LTA"? Alternatively, is it sufficient if they have "access" to the technology in other ways, labelled by some "access to all"?

Before addressing these questions, a note on the terminology is required. Müller (2021) criticises both terms as misnomers, pointing out correctly that actual licensing to all "*won't happen in practice thanks to patent exhaustion*" (unless one considers licensing by exhaustion). He also criticises the notion of "access to all", arguing that "*the term 'access' is nebulous at best and mendacious at worst*." Indeed, "*access*" may mean little more than that SEP holders condone patent infringement, which is not a satisfactory solution.

Authors have weighed in on one or the other side of the debate; Geradin (2020, pp. 16-21) provides an overview of the debate, and the SEPs Expert Group (2021, Section 6.1) also discusses the issue. Kühnen (2019, p. 964), Greene (2019, p. 1085), and Dornis (2020), for instance, perceive an obligation on the part of the SEP holder to license to any interested party. Others take the opposing view (e.g., Layne-Farrar and Stark, 2020), and Borghetti et al. (2021, p. 1) come to the conclusion "*[…] that there are only very limited doctrinal grounds to impose an LTA ['license to all'] obligation on SEP holders that made a FRAND commitment.*" The authors (Borghetti et al., 2021, p. 45; 2020, p. 4) propose four ways in which, in the case of device-level licensing, upstream firms could deal with SEPs.

It is a legal question, and beyond the scope of this paper, if SEP holders are obliged on doctrinal grounds to grant a licence to any party seeking one. Questions of legal doctrine, however, should not guide policy decisions in such a case. What matters is that the licensing process should promote the adoption of IoT technologies and stimulate IoT-related innovation and entrepreneurship. These goals are furthered by legal certainty and low transaction costs—conditions that are not well satisfied by the methods that Borghetti et al. (2021, p. 45; 2020, p. 4) propose.

To start with, "*concluding non-assertion agreements*" could work if those agreements were comprehensive, unconditional, and unlimited. However, such agreements might be perceived as problematic by SEP owners (SEPs Expert Group, 2021, Section 6.1.3). All other methods would expose upstream firms to legal uncertainty (e.g., Kühnen 2019, p. 965) and thus create transaction costs, in particular "*selling products to licensed downstream manufacturers*" and "*not having any license at all if the patent owner has a policy of not monetising its patents and thus not having a licensing program*." Also "*'have made' rights*"[17] do not create legal certainty, except for the device maker's direct suppliers (Geradin, 2020, p. 19-20).

Furthermore, "have made" rights restrict upstream competition (see Section 7.2) and create additional transaction costs since a separate "have-made" right would be required for each supply relationship. For example, with two suppliers and 100 device makers, and assuming that each device maker sources from both suppliers, 100 licences and 200 have-made rights would be required with device-level licensing, compared to two licences with component-level licensing.

Regarding transaction costs, Borghetti et al. (2021, p. 3) state that "*the ordinary industry practice often follows ATA because of: (i) the transaction costs savings achieved in negotiations with one group of licensees […]*". Some members of the SEPs Experts Group (2021, p. 76) apparently embrace this argument. However, this argument is unconvincing in light of the discussion of transaction costs in Sections 3 and 5, which showed that the number of potential licensees may differ by a factor of thousand between licensing on the highest vs. the lowest level of the value chain.

To conclude, SEP licensing should be practised in a way that provides legal certainty to all firms in the value chain, thus reducing transaction costs related to possible opportunistic behaviour. The various ways to implement downstream-only licensing suggested by Borghetti et al. (2021) fail to provide this legal certainty and entail an increase in transaction costs on top of those already discussed in Sections 3 and 5. The way to achieve legal certainty for all firms in the value chain with minimal transaction costs is to license at the highest possible level of the value chain, since all downstream firms would be licensed by way of exhaustion. A caveat is that some SEPs are first implemented on lower levels of the value chain (see Section 5.4).

7.2. Upstream competition

One of the solutions suggested by Borghetti et al. (2020), "have-made" rights, has the additional downside of restricting upstream market competition. If suppliers can offer fully licensed products, competition in the supplier industry is more intense compared to a situation where they need to rely on "have-

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[17] In a summary of their article (Borghetti et al. 2021) posted on the website of 4iP Council (Borghetti et al. 2020, p. 4), the authors additionally mention "have made" rights as a method of granting access to a standard. A "have-made" right would be granted by a device maker (which itself had been licensed by the SEP owner) to a supplier for the specific purpose of producing inputs for the device maker.

made" rights: in the first case, an alternative supplier could relatively easily compete with existing suppliers, be it on the basis of cost or of novel product features, by simply offering its product to buyers. In the second case, a "have-made" right would first have to be granted by the company to be supplied. Thus, the objective of promoting competition also provides grounds for licensing at higher levels of the value chain.

Related to this, Greene (2019, p. 1085) argues that a firm refusing to grant an SEP licence to specific parties "*should be presumed to have market power and to have participated in exclusionary conduct with anticompetitive effects.*" In the same vein, the Association of Global Automakers and the Alliance of Automobile Manufacturers (2019, p. 5) state in their Amicus Brief on the FTC proceedings against Qualcomm, Inc.: "*Exhaustion eliminates market frictions and promotes innovation and competition by ensuring that downstream purchasers can use, resell, or innovate around a patented product with no risk of infringement liability.*" In turn, as Kurgonaitė et al. (2020, p. 140) put it, "*exclusion [of entities from the intermediary market through selective licensing] might restrict R&D at intermediate levels and/or limit the ability to compete for all customers. If the intermediary is neither licensed itself, nor covered by the 'have made' provisions of a downstream* licence, *this might chill incentives to innovate.*" Geradin (2020, p. 21) concurs.

In conclusion, the policy goal of promoting competition also inclines to licensing higher up in the value chain.

7.3. Implications for innovation and entrepreneurship

Uncertainty is known to affect innovation negatively (e.g., Stern, 2017). Under device-level licensing, implementing IoT components into products is riddled with uncertainties, as discussed above. Cost uncertainty exists because device makers do not know what royalties will be demanded, when, and by how many SEP holders. Partly, this is because some patent holders become visible and make licence claims only once a product has achieved market success. In addition, device makers face legal uncertainty since they cannot avoid patent infringement—it is impossible to obtain a licence from every SEP holder—and are thus constantly under the threat of infringement litigation. These uncertainties are particularly severe since device makers typically have no understanding of the IoT technologies in question, and are further compounded for SMEs by resource constraints. In addition to uncertainties, device-level licensing implies much higher transaction costs overall and in particular for device makers, as discussed in Sections 3 and 5.

This situation is harmful to device-level innovation. Facing the above uncertainties and transaction costs, firms may delay the adoption of novel IoT technologies or shelve it altogether, resorting to older and more likely upstream-licensed technologies, or e.g. keep a device connected with Wifi only instead of integrating cellular technology; their innovation process may be slowed down because of additional technical and legal work necessitated by licensing requests; royalty demands later in the process may require price increases that irritate customers, or may make a firm's business model unsustainable; investors may be reluctant to provide financing to a venture facing the uncertainties of IoT SEP licensing or even the threat of litigation; and potential entrepreneurs, worried about IP issues, may refrain from founding an IoT device firm in the first place. Upstream, the practice of device-level licensing also impacts innovation negatively, as Continental and Denso (2019, p. 8) state in their amicus brief: "*The SEP-holders' discriminatory approach to licensing creates a crippling uncertainty for upstream manufacturers that suppresses their willingness and ability to innovate.*" While these firms are not neutral to the debate, their argument is economically sound: the incentive to innovate is reduced if selling the innovative product requires that potential buyers be licensed themselves and that they grant a "have-made" right.

In contrast, the possibility of acquiring fully licensed IoT components will accelerate the innovation process by making the costs of such components and the associated licences predictable, creating legal certainty, and allowing the implementation of IoT technology at low transaction costs. Thus, the goal of promoting innovation and entrepreneurship in device industries also inclines to upstream licensing.

7.4. Aggregate returns to standard development

SEP owners must receive an appropriate return on their investments in technology development and the risks taken, both for reasons of fairness and in order to maintain innovation incentives for future standard generations. On the other hand, they should not be over-rewarded.

In this context, one needs to consider that the 4G and 5G standards were developed through a collaboration between all interested parties, without the "*competitive environment before the industry has been locked into the standard (ex ante)*" to which the EC's Guidelines on the Applicability of Article 101 TFEU refer in Article 289 when discussing methods to determine FRAND royalties. Such collaboration is typically accepted by antitrust authorities in the interest of efficiency, but under the assumption of competition in the downstream market. However, this competition is partly absent: the relevant downstream market is nowadays to a large extent the market for SEP licences, and on this market sellers do not compete since, by definition, SEPs are complements, not substitutes. As already discussed in the context of patent pools (Section 5.3), the independent pricing of complements tends to lead to even higher prices than collusion or a monopoly (Cournot, 1838). Thus, a situation results in which firms collaborate in R&D without competing in the relevant downstream market (the market for SEP licences)—not a comfortable situation from an antitrust perspective.

These considerations raise the question what aggregate, overall returns to contributions to standard development are appropriate. These comprise returns realised through sales of own products, cross-licensing, and explicit SEP royalties, and they need to be juxtaposed to the overall costs of developing the respective standard. Such a cost-based approach to FRAND valuation (Friedl and Ann, 2018) is in line with the Guidelines on the Applicability of Article 101 TFEU, Article 289. While the Article dismisses cost-based methods, it does so on purely practical grounds, "*because of the difficulty in assessing* *the costs attributable to the development of a particular patent or groups of patents.*" But even if these concerns are justified, a calculation of *aggregate* costs and returns should provide a valuable anchor for assessing the conformity of royalties to FRAND rules.

Considering overall returns to standard development raises the question of whether and to what extent price differentiation to increase licensors' revenues is actually necessary for them to achieve a fair return on their R&D investments (cf. Geradin, 2020, p. 21-22). Judging by the strong increase in the number of SEP owners from 2G to 5G[18], contributing to the development of cellular technologies would seem to be an attractive business. And the projected numbers of IoT devices suggest that the IoT in particular will be profitable: Ericsson (2019, p. 17), e.g., predicts for 2025 a global number of 5 bn cellular IoT connections. On top of this comes royalty income from large numbers of non-IoT cellular devices: for 2023, about 1.5 bn smartphone shipments per year are predicted, and many of them can be expected to support 5G.[19] While the actual growth of the IoT lags behind the optimistic predictions, these numbers suggest that even with a low, fixed royalty for all IoT industries SEP owners may realise attractive returns on their R&D investments.

8. Discussion and conclusions

The debate about where in the value chain IoT SEPs should be licensed has been going on for some time. Geradin (2020) and the SEPs Expert Group (2021) list most of the arguments that have been advanced. Yet an empirical perspective on the firms that will generate IoT applications—device makers, and in particular SMEs and startups—is largely absent. Furthermore, contradictory claims are often juxtaposed in the literature without weighting, for instance, with respect to the claimed transaction costs advantages of one or the other licensing approach. This paper contributes to the debate by presenting results of a qualitative empirical study based on interviews with 18 individuals from 12 firms, comprising more than 11h, complemented by a discussion of economic arguments related to transaction costs, price differentiation, and industry development. Based on the analyses in this paper, I discuss in the following principles for a viable process of IoT SEP licensing, weigh the pros and cons of potential solutions, and derive recommendations for policy makers.

8.1. Principles for IoT SEP licensing

The SEPs Expert Group (2021, p. 182) formulates three principles for licensing IoT SEPs in the value chain: "*(i) licensing at a single level in a value chain; (ii) a uniform FRAND royalty irrespective of level of licensing; and (iii) ability to pass down the value chain a FRAND royalty.*" These are sensible

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[18] Bekkers et al. (2002) report 14 different owners of essential IPR in GSM, while my estimate based on IPlytics (2019) is that there are about 500 individual parties that have declared 5G SEPs as of November 2019 (see Footnote 9). See also SEPs Expert Group Report (2021, p. 36).

[19] See https://www.statista.com/statistics/263441/global-smartphone-shipments-forecast/.

suggestions from an economic perspective. The Group furthermore makes a number of detailed proposals (summarised on pp. 180-186) addressing various aspects of the licensing process.

What is absent in the list of proposals is an explicit endorsement of the goal of the EU Commission (2017, p. 7) that "*[t]ransaction costs relating to the negotiation of a licence should be kept to the minimum necessary*", which is generally desirable from the perspective of societal efficiency. In fact, some of the proposals ignore the technology-related limitations of device makers and of SMEs in particular as licensees (for instance, Proposals 51 and 53 requiring an SEP holder to provide high level claim charts to the implementer), and others would even increase transaction costs for device makers (e.g., Proposals 54 and 55 regarding an implementer's duty, under certain conditions, to "*proactively seek licences, prior to commercializing standard-compliant products*", and Proposals 60 and 61 obliging an implementer "*to record type/model of product at time of market introduction into a SDO database*"). Furthermore, the goal of promoting innovation and entrepreneurship by downstream firms in the IoT is not mentioned in the SEPs Expert Group's (2021) report. Any concerns about innovation in the report refer to upstream innovation (pp. 22, 191), not to device-level innovation. Yet, this is what the IoT is all about. I propose adding these goals to the list of IoT SEP licensing principles:

(iv) Licensing at a value chain level where transaction costs are minimal.

(v) Licensing in a way that promotes downstream innovation and entrepreneurship.

In the following, I discuss various licensing levels with regard to these principles.

8.2. Device-level licensing

As discussed in the preceding sections, device-level licensing implies high transaction costs. Even if all of the SEPs Expert Group's (2021, pp. 180-186) proposals were implemented—which is highly unlikely—the problems raised in Sections 3 and 5 remain: Device makers are ignorant of IoT technologies and related SEPs, are often SMEs and startups and thus resource constrained, and more numerous than baseband processor makers, plausibly by a factor of 1,000 or more. As a result, it will be difficult to achieve consistent licensing across all firms in an IoT device industry. Furthermore, the transaction cost burden and legal and cost uncertainties will hamper device-level innovation and entrepreneurship.

The suggestion by the SEPs Expert Group (2021, p. 119) SEP holders could charge "*lower or no licence fees […] for lower volume sales up to a certain amount per year*" would mitigate, but not solve the problem: lower fees would leave the transaction cost issues unchanged, and with no fees, these problems persist for firms above the threshold, which likely will still be many more than potential upstream licensees. Furthermore, some members of the SEPs Expert Group (2021, p. 42) expressed the view that "*SEP holders are unlikely to enforce their SEPs where royalties at stake are not significant enough to justify the cost of licensing. […] in particular with SMEs, these SEP licensors will not be aggressively pursuing royalty revenues.*" While this may be the case, implementers can never be certain, and the resulting uncertainty is harmful to their business. Finally, the SEPs Expert Group's (2021, p. 147) proposal of a "*specialized mediation institute for FRAND licensing disputes*", which according to the Group "*could be particularly helpful for SMEs […] to determine whether an offer an SME has received from a SEP holder is indeed non-discriminatory*" also misses the wider problems of implicit discrimination between implementers that are and those that are not licensed and of high transaction costs.

In sum, device-level licensing has inherent disadvantages with respect to transaction costs. It is likely to lead to inconsistent licensing, and hinder innovation and entrepreneurship in the IoT.

8.3. Licensing on the level of the baseband processor

Licensing on the level of the baseband processor should imply considerably lower transaction costs than device-level licensing, due to the low number of licensees and their high level of pertinent technological competence. By the same token, it should be easier to achieve consistent licensing. For device makers, SMEs and startups in particular, the chance to procure fully licensed IoT modules should boost innovation and entrepreneurship by simplifying processes and avoiding legal and cost uncertainty.

Questions need to be addressed with respect to price differentiation and exhaustion. Price differentiation of SEP royalties, as discussed in Sections 4.1 and 6, can allow serving the low end of the market without sacrificing margin at the high end, and thus increase the licensor's revenues. Interviewees from SEP licensors considered price differentiation possible at the device level only, but it should also be practical at the baseband processor level. As discussed in Section 6.3, baseband processors also of IoT cellular modules differ considerably in performance, which should provide a basis for price differentiation of royalties. The SEPs Expert Group (2021, Proposals 35–37) makes similar suggestions. Furthermore, the considerations in Section 7.4 on aggregate royalties suggest that SEP owners, given the huge expected number of IoT devices, would realise an attractive return consistent with FRAND rules even with low royalties, implying less of a need for price differentiation.

Finally, the technical question as to what level of the value chain SEPs are first implemented on needs to be resolved (see Section 4.2). How many are not, or not only, implemented in the baseband processor? If these patents are few, then charging royalties to baseband processor makers while granting free licences to makers of complementary, SEP-implementing components may well be sufficient.

In summary, licensing on the level of the baseband processor does well on the principles regarding transaction costs and innovation stated above. It should also allow SEP holders to generate a fair return on their R&D investments.

8.4. Licensing on the level of the NAD

The NAD is situated between the baseband process and the device, in several respects. Technically, the NAD integrates the processor and is itself integrated into the device. Accordingly, in the value chain chipset makers supply to NAD manufacturers, and NAD manufacturers to device firms. In terms of technical and patent competence related to IoT standards, NAD manufacturers will be less knowledgeable than baseband processor makers, but more than device makers. The number of firms in the industry maybe be somewhat higher than at the processor level, but will be considerably lower than at the device level. Thus, transaction costs will be somewhere between those for processor- and for device-level licensing. In terms of size, NAD manufacturers are unlikely to be small firms due to the economies of scale of their business, and so they should be less resource constrained than the typical device firm. The potential issue of multi-level licensing (see Section 5.4), if it exists, should be resolved since the NAD integrates further networking-related components in addition to the baseband processor; price differentiation should be possible since NADs are likely more specific to the use case than the processor (see SEPs Experts Group, 2021, Section 6.2); and the goal of promoting innovation and entrepreneurship in the IoT would be advanced since device makers could procure fully licensed components. Furthermore, it might be possible to use a forgery-proof version of the (device-level) International Mobile Equipment Identity (IMEI) number to check if a given device is licensed. Device makers would be licensed by exhaustion, though baseband processor manufacturers that are not also NAD makers would still face the issue of legal uncertainty discussed in Section 7.1.

In sum, licensing at the NAD level fulfils Principle (iv) regarding transaction costs considerably better than device-level licensing and probably not as well as licensing on the level of the baseband processor, but may alleviate potential practical problems of the latter. In terms of promoting innovation and entrepreneurship by device makers, Principle (v), it should serve as well as processor-level licensing.

8.5. Conclusions

For smartphones, SEP licensing is commonly practiced at the device level, and similarly for several other ICT standards (e.g., SEPs Expert Group, 2021, pp. 77-79). Yet in nearly all other industries, the licensing of patents takes place at the level of the value chain where the corresponding inventions are first implemented. This is reflected in the U.S. Uniform Commercial Code (§ 2-312 (3)), which defines upstream licensing as the default: "*Unless otherwise agreed a seller […] warrants that the goods shall be delivered free of the rightful claim of any third person by way of infringement or the like […]*" Similar provisions exist in the UN Convention on Contracts for the International Sale of Goods (CIGS), Art. 42, and national laws ("warranty of title").

The analysis presented in this paper shows that there are good reasons why upstream licensing is the default, lending empirical support to arguments made earlier (Pohlmann, 2017; Geradin, 2020, p. 17; Schneider, 2020; SEPs Expert Group, 2021), with a focus on startups: downstream firms have no understanding of the technology at hand and the patents that cover it, which hinders fair licensing negotiations; furthermore, for widely applicable technologies they are typically much more numerous than the upstream component suppliers. Device-level licensing also flies in the face of Adam Smith's efficiency-increasing principle of the division of labour. Responsibility for patent licensing should rest with those parties that have an understanding of the technologies that embody the patents under consideration—in the present case, the makers of baseband processors. Upstream licensing is clearly advantageous in these regards.

This study has raised a number of questions: (1) What share of SEPs are actually implemented outside the baseband processor, apart from just referencing outside components such as an antenna? (2) How could price differentiation be based on the performance of the baseband processor? (3) What are, roughly, the aggregate development costs of the main IoT standards, and what royalties would be required to generate a fair return on these costs? Furthermore, the findings in this study suggest two additional licensing principles in addition to those formulated by the SEPs Expert Group (2021, p. 182): licensing at a value chain level where transaction costs are minimal; and licensing in a way that promotes downstream innovation and entrepreneurship. It would be helpful for the industry if policy makers launched projects to objectively assess these questions, and if they adopted the proposed licensing principles.

The IoT offers infinite opportunities to innovators, entrepreneurs, and society. Making IoT SEP licensing as simple as possible will help to realise these opportunities.

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