Royalty Stacking and Standard Essential Patents: Theory and Evidence from the World Mobile Wireless Industry*

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Abstract

The royalty stacking hypothesis states that each standard essential patent (SEP) holder will charge excessive royalties to downstream manufacturers. Royalty stacking creates a Cournot-complement problem, hurts innovation and raises prices paid by consumers. With an equilibrium royalty stacking model with entry we also find that, as the number of SEP holders increases and becomes large: (i) downstream sales fall; (ii) downstream concentration increases; (iii) each SEP holder prices *less* aggressively and her margin *falls*; (iv) the equilibrium aggregate royalty rate increases almost dollar by dollar if manufacturing unit costs fall in one dollar or quality improvements increase consumers' willingness to pay in one dollar; (v) eventually, the downstream industry may be priced out of existence.

We look for evidence of royalty stacking in the world mobile wireless industry, where the number of SEP holders protractedly grew from 2 in 1994 to 130 in 2013. Contrary to the predictions of royalty stacking theory, between 1994 and 2013: (i) the (non-quality adjusted) average selling price of a device fell 8,1% per year on average; (ii) the number of devices sold each year rose 62 times or 20,1% per year on average; (iii) the number of device manufacturers grew from one in 1994 to 43 in 2013; (iv) since 2001 concentration fell and the number of equivalent manufacturers rose from six to nine; (v) the average gross margin of SEP holders no trend, neither increasing nor decreasing.

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1. Introduction

Many electronic devices we use—e.g. phones, personal computers, laptops, televisions or audio systems—rely on technological standards that make them interoperable. Technology standards enable the owner of an iPhone to call a friend subscribed to a different network who uses a Samsung Galaxy, switch to wifi when sitting in a cafe, or film a video and later watch it on her TV, laptop or tablet. And thanks to standards, components, devices, networks and applications are designed, manufactured and deployed by a myriad of different firms that specialize and exchange technologies. Yet an influential academic literature argues that technological progress in these industries is under threat because each owner of a standard essential patent (SEP)—a patent that reads on an innovation that is potentially essential for the standard to work—can charge royalties far in excess of the patent's economic value to each manufacturer.

According to the literature, excessive royalties result from the interaction of two economic mechanisms, hold-up and royalty stacking. After standards are set by the industry's standard setting organizations (SSOs), manufacturers sink investment costs for implementation specific to the standard. The hold-up argument suggests that each SEP holder can threaten the manufacturer with an injunction after the manufacturing costs are sunk, extract quasi rents up to the value of using the standard, and partly expropriate the manufacturer, notwithstanding the licensing commitment required by several SSOs from the patentees to license their SEPs on fair reasonable and non-discriminatory (FRAND) terms[1].

Worse, standards involve hundreds, if not thousands, of complementary SEPs. Because SEP owners bargain for royalties independently, one excessive royalty stacks above the other and together add up to an unsustainable high charge.[2] Some scholars have argued that this type of royalty stacking slows down product introduction, increases prices paid by consumers and retards or might even derail the next round of innovation.

Whether patent holdup and royalty stacking are slowing down innovation and hurting consumers of SEP-intensive goods has been somewhat controversial, however. While antitrust agencies and some recent court decisions on patent licensing cases have voiced concerns about hold-up, the academic literature that has tried to find out whether hold-up and royalty stacking exists and causes economic inefficiencies has been largely inconclusive.[3] For example, Gerardin, Layne-Farrar,

[1] The Federal Trade Commission (2011) defines patent hold-up as follows:

> 'Hold-up' describe[s] a patentee's ability to extract a higher license fee after an accused infringer has sunk costs into implementing the patented technology than the patentee could have obtained at the time of [the accused infringer's] design decisions.

[2] As defined by Lemley and Shapiro (2007):

> The term "royalty stacking" reflects the fact that, from the perspective of the firm making the product in question, all of the different claims for royalties must be added or "stacked" together to determine the total royalty burden borne by the product if the firm is to sell that product free of patent litigation.

For academic literature concerned with holdup and royalty stacking see, for example, Shapiro (2001), Lemley (2002), Swanson and Baumol (2005), Farrell et al. (2007), Lemley and Shapiro (2007) and Miller (2007).

[3] For example, FTC (2011), Judge Robart's decision on the Motorola vs. Microsoft (2012) case.

and Padilla (2008), Barnett (2014) and Egan and Teece (2015) note that there is little empirical evidence that SEP hold-up actually occurs. And recently Galetovic, Haber and Levine (2015) could not reject the hypothesis of no SEP hold-up. Specifically, they found that over the past 16 years quality-adjusted prices of SEP-reliant products fell at rates that are not just fast compared to a classic hold-up industry, but that are fast against patent-intensive, non-SEP-reliant products; indeed, they fell fast relative to the prices of almost any other good, suggesting fast and sustained innovative activity. Moreover, they also found that after the courts made it harder for SEP holders to hold-up manufacturing firms, the rate of innovation in SEP-reliant industries did not accelerate relative to other industries.[4]

At the same time, several papers have argued that the proposed remedies to mitigate SEP hold-up may result in royalty rates that are too low, thereby reducing the incentives for firms to innovate (Elhauge 2008, Ganglmair, Froeb, and Werden 2012). Related to this, Schmalensee (2009) and Sidak (2009) argue that the ex-post bargaining position of a monopsonistic collection of manufacturers is much stronger than the bargaining position of patent holders. This reduces the expected returns to inventions and lowers investment in the costly, risky process of developing and patenting new technologies. Of course, reverse hold-up also should retard innovation, but for the opposite reasons than hold-up and royalty stacking.

In this paper we contribute to this debate with both theory and evidence from the mobile wireless industry. Specifically, we focus on the widely used third generation (3G) and fourth generation (4G) wireless cellular standards defined by the third generation partnership project (3GPP). The effects of royalty stacking should be glaring in this industry because, as Figure 1 illustrates, during the last 20 years the number of SEP holders for 3G and 4G standards grew from 2 in 1994 to 130 in 2013 and the number of SEPs rose from a fewer than 150 in 1994 to more than 150,000 in 2013. Indeed, the wireless cellular standards have been at the center of the debate about competitive harm due to high aggregate royalties.[5]

On the theory front we study a model where manufacturers decide whether to enter and sink entry costs before each SEP holder individually and simultaneously sets her royalty rate—there is both hold-up and royalty stacking. Then, taking the aggregate royalty rate as given, manufacturers compete in the product market by setting quantities and this determines the equilibrium quantity and the equilibrium price. On the supply side, we follow Genesove and Mullin's (1998) and model the intensity of price competition with a conduct parameter, which nests most known homogeneous-

[4] There is a broad consensus in the legal literature that after the 2006 Supreme Court's *eBay Inc. v. MercExchange LLC* decision, firms that license their patents face greater difficulty in meeting the Supreme Court's "four-factor test" for a permanent injunction.

[5] For example, Lemley (2002) states:

> Time and time again, we have seen this sort of royalty-stacking problem arise. One great example is 3G telecom in Europe. The standard-setting organization (SSO) put out a call for essential patents, asking which they must license to make the 3G wireless protocol work and the price at which the patent owners would license their rights. 3G telecom received affirmative responses totaling over 6,000 essential patents and the cumulative royalty rate turned out to be 130%. This is not a formula for a successful product.

good oligopoly models. On the demand side, we use the family of constant pass-through demand functions of Bulow and Pfleiderer (1983) with bounded willingness to pay and unbounded price elasticity as quantity tends to 0.

Our first result is well known: because each of the m SEP holders behaves as an input monopolist when setting her royalty rate, individual royalties stack one upon the other and in equilibrium the Lerner margin is m times the Lerner margin that would be set by a monopolist who owns all SEPs (see Shapiro (2001)). Hence, regardless of the intensity of price competition and of the form of the demand curve, the aggregate royalty rate increases with the number of SEP holders and so do downstream equilibrium prices. Consequently, as royalty stacking worsens, the equilibrium quantity falls, ceteris paribus (see, for example, the appendix in Lemley and Shapiro (2007)).

We find several additional observable implications of royalty stacking. First, as the number of SEP holders grows, they set individual royalties that extract an increasing fraction of consumer willingness to pay. Indeed, when the number of SEP holders is large, the aggregate royalty rate increases almost dollar by dollar with higher willingness to pay (due, for example, to quality increases) or lower downstream manufacturing costs (due, for example, to productivity increases). Therefore, because equilibrium individual royalties are endogenous to downstream costs and willingness to pay, the effects of royalty stacking cannot be undone by "other" countervailing cost or quality shocks.

Second, as the number of SEP holders increases, fewer manufacturers enter and equilibrium industry concentration rises. Thus, prices rise and quantity falls further. Eventually, entry ceases and the downstream industry disappears if sales fall enough and the industry's net revenue becomes insufficient to pay for sunk investments; or if stacking yields a royalty rate that exceeds the upper bound on consumer willingness to pay.

Third, and perhaps contrary to conventional wisdom, we find that the equilibrium individual royalty rate and SEP holder margins *fall* with the number of SEP holders—as the number of SEP holders increases, each SEP holder prices less aggressively. The economics is that, as stacking worsens and prices rise, the gain from unilaterally and marginally raising the individual royalty rate (which is proportional to downstream aggregate sales), falls relative to the revenue loss wrought by selling fewer units downstream; this makes less aggressive pricing optimal. While this result holds with bounded willingness to pay; fort demand functions exhibiting unbounded willingness to pay (as, for example, the canonical constant-elasticity demand curve) individual royalty rates would rise with stacking. Nevertheless, we also show that this class of functions has implausible implications. In particular, the market disappears if the number of SEP holders is similar to the limit of the price elasticity of demand as p grows very large. In other words, for any plausible value on the price elasticity of the demand for phones the market would have disappeared long before the 130 SEP holders counted in 2013.

Based on the observable implications, we test for the presence of royalty stacking by examining the evolution of prices, quantities, concentration and gross margins in the world mobile wireless device industry between 1994 and 2013. In examining the dynamics of prices, sales and concentration we do not find support for the royalty stacking hypothesis. As Figure 1 shows, between

1994 and 2007 the number of SEP holders grew from 2 to 130 and the number of declared SEPs grew more than 380 times. Yet the average selling price of a device, unadjusted for quality and composition, fell to one fifth its initial level, from \$853 in 1994 to \$173 in 2007, or -11.5% per year on average. Since 2007 the average price of a device of the same generation has fallen between 52% and 84% (or between 12,2% and 30,5% per year). Thus, we find no evidence of rising prices due to royalty stacking (or any other cause).

As prices have fallen, device sales have risen. In 1994 the one manufacturer (Ericsson) sold 29 million devices. In 2007, by contrast, 44 manufacturers sold 1.1 billion devices, a 39-fold increase or 26,3% per year. Since 2007, device sales grew further, to almost 1.8 billion in 2011, or 10% per year. Industry revenues, which increased more than eight times between 1994 and 2007 and about 50% since then. Of course, revenue growth is just the result of growing sales, which more than compensate price falls. But it just confirms that as the number of SEP holders has increased, the industry expanded fast.

The royalty stacking theory also predicts that the industry will concentrate as the number of SEP holders rises. Yet the number of device manufacturers steadily grew from one in 1994 to 20 in 2002, then jumped to 40 in 2006 and then stabilized around that number. Moreover since 2001 the number of equivalent device manufacturers grew from around six to about nine in 2013.[6] Hence, market concentration fell.

We also collected financial data on the universe of firms that participated in the development of the global third and fourth generation wireless cellular standards—over 300 firms— between 1994 and 2012 and for each computed gross margins year by year. We coded each firm by the number of SEPs it can assert and separated the sample between firms who held at least one SEP and firms who hold no SEP (until a firm declares its first SEP, it is classified as non-SEP holder). The average gross margin of SEP holders hovers between 30% and 35%, but shows no downward trend. The average gross margin of non-SEP holders is higher and fluctuates more, but there is no sustained, long-run trend. We repeated the exercise restricting the sample to device manufacturers. Now the average gross margin of SEP holders hovers around 30% , but again shows no trend. And again, the average gross margin of non-SEP holders is higher and fluctuates more, but there is no sustained, long-run trend.

Our test of the theory is neither structural nor exploits an exogenous event. Instead, it directly looks at the evolution of observed yearly averages. This approach may perhaps be a bit unusual, yet it is appropriate for three reasons. First, the literature claims that royalty stacking can seriously harm the performance of the industry, i.e. affect its long-run equilibrium performance. Thus royalty stacking is neither a marginal effect nor one among many other shocks affecting downstream manufacturing. On the contrary, when the number of SEP holders steadily grows over many years, royalty stacking is a protracted force which will, sooner or later, become the overwhelming determinant of industry performance, or so the literature and the model imply. Therefore, if royalty stacking is present and worsening, it should become apparent in the long-run evolution of observable equilibrium prices, quantities, structure, and margins. Second, while

[6] Let $\mathcal{H}$ be the Herfindahl index. The number of equivalent firms is equal to $\frac{1}{\mathcal{H}}$, or the number of firms of equal market shares that would produce the same Herfindahl index. See Adelman (1969).

"everything else" is not constant over a 20-year period, our model shows that equilibrium individual royalties are endogenous to downstream costs and willingness to pay; for this reason, the effects of royalty stacking cannot be undone by "other" countervailing cost or quality shocks. Last, our data are yearly averages from almost all worldwide mobile wireless device sales.

The rest of the paper is organized as follows. Section 2 provides some background of the role of SSOs and SEPs in the mobile wireless industry. Section 3 presents a long run equilibrium model of royalty stacking, and highlights some of the key observable implications from the model. Section 4 discusses evidence from the mobile wireless industry in relation to the key observable implications from the model. Section 5 concludes. We provide further results from the generalization of the model and further description of the data in Appendices A and B.

2. SSOs and SEPs in the mobile wireless industry

Standard setting organizations (SSOs) are industry groups formed to solve complex technical problems in different technology areas which address the needs of a large number of adopters. Standards are particularly important in the Information and Communications Technology (ICT) industry, where multiple devices need to connect and communicate with each with interoperable technology solutions.

Before there were wireless cellular standards, mobile phone users could not travel to another country and still make calls. Different technologies were used by different countries and firms, each requiring heavy investments. Thanks to technology standards, now the owner of Smartphone A can talk with the owner of Smartphone B—even though A and B are made by different manufacturers and operate on networks built and owned by different companies. More, smartphone A can also share pictures, videos, and other media at high speeds. The development of a new technology begins in SSOs years before products reach the market.

To overcome incompatible standards the telecommunications industry organized itself around several SSOs. Most wireless systems deployed in the world today have adopted the so-called third-generation (3G) and fourth-generation (4G) wireless cellular standards defined by a body called the third generation partnership project (3GPP).[7] 3GPP was formed in 1998 to develop a common wireless cellular system for Europe, Asia and North America. It brought together seven telecommunication SSOs and is responsible for generating the standards endorsed by the member SSOs. One of the seven SSOs, the European Telecommunications Standards Institute (ETSI), is in charge of the day-to-day running of 3GPP. Moreover, most firms participating in 3GPP are members of ETSI. Membership in 3GPP is voluntary (i.e., any firm can become a member), and technologies are chosen to become standards based on consensus or majority voting amongst the members. Nearly 500 organizations participated in the formation of these standards. They have spent around 3.5 million man hours in around 850 working meetings between 2005 and 2014.

In the evolution from 2G to 4G technologies, maximum download speeds have increased about 12,000 times from 20 *kilo*bits-per-second in 2G to 250 *mega*bits-per-second in 4G. Standards also allow specialization (see Figure 2). Some firms develop communications technologies (the "IP

[7] Baron and Gupta (2015) discuss and describe the process of 3GPP standard setting in detail.

innovators"); others create products utilizing these technologies: devices such as smartphones and tablets, and network infrastructure such as base stations and servers (the "manufacturers"); and yet others specialized in deploying large networks and providing the wireless services to consumers (the "operators" or "service providers").

One of the main functions of 3GPP is to develop IPR policies that foster investments in the R&D that creates the standards and that facilitate its fast diffusion and adoption. Typically, as an incentive for firms to participate in and contribute to the standard setting process, the participants are allowed to seek IP rights (IPR) for their technical contributions and investments they make during the standardization process.[8] SSOs usually require firms to declare the patents that are potentially essential to the implementation of the standards. And because all manufacturers of a standard need a license from patent owners holding standard-essential patents, the IPR policies of several SSOs require their members to publicly declare any IPR that may become essential to the implementation of the standard, and to license them to any interested party on "fair, reasonable and non-discriminatory terms" (FRAND).[9] All seven SSOs that comprise 3GPP require firms to declare the patents that are potentially essential to the implementation of the standards. Firms declare their potentially essential patents by filling declaration forms, each of which are maintained in a database by ETSI.

Figure 1 shows the time series of the number of SEPs and the number of firms owning these SEPs. During the last 20 years the number of SEP holders for 3G and 4G standards grew from 2 in 1994 to 130 in 2013 and the number of SEPs rose from fewer than 150 in 1994 to more than 150,000 in 2013. The number of SEPs, or complementary inputs for producing mobile wireless products, and the number of firms owning SEPs has been increasing over time Thus, if a royalty stacking problem exists, it should be worsening over time.

3. A long-run equilibrium model of royalty stacking

3.1. The model

In this section we present a simple equilibrium model of patent holdup and royalty stacking with endogenous entry and investment. Our aim is to compare the long run equilibrium of an industry with and without holdup and royalty stacking.

Demand Following Genesove and Mullin (1998) we assume that demand for the final good (e.g. phones) D is of the form

$$Q = D(p) \equiv S \cdot (v - p)^{\gamma}\,; \tag{3.1}$$

[8]Some standards bodies produce open standards, i.e., participants forfeit their IP rights when contributing a technology into the standard, while others produce entirely proprietary standards, i.e., standards controlled by a single firm or a group of entities.

[9]Although The IP policies of SSOs vary widely, FRAND terms are a common practice in the most commonly used ICT standards for wireless technologies. For a recent survey of IPR policies across SSOs, see Bekkers and Updegrove (2012).

here Q and p have obvious meanings and S is the size of the market.[10] Note that the inverse demand is $P \equiv D^{-1}$,with

$$P(Q) = v - \left(\frac{Q}{S}\right)^{\frac{1}{\gamma}}.$$

When $\gamma, v > 0$, this demand function nests, as special cases, the linear demand used by Lemley and Shapiro (2006) ($\gamma = 1$); the quadratic demand curve ($\gamma = 2$); and, when $v, \gamma \to \infty$ with $\frac{\gamma}{v}$ constant, the exponential demand function. It is strictly concave if $\gamma \in (0, 1)$ and strictly convex if $\gamma > 1$. Regardless, it has the appealing property that, with the exception of the limiting exponential demand, willingness to pay is finite and bounded from above by v.

Now the price elasticity is

$$\eta(p) = \gamma \frac{p}{v - p},$$

which increases with price. Moreover,

$$\lim_{p \to v} \eta(p) = \gamma \cdot \lim_{p \to v} \frac{p}{v - p} = \infty.$$

Thus with bounded willingness to pay the price elasticity of demand rises without bound as p rises or Q falls. This is a fact is of some importance below.

Remark 1. *In the Appendix we consider the family of demand functions*

$$Q = D(p) \equiv S \cdot (v + p)^{\gamma}, \tag{3.2}$$

with $\gamma < 0$ *and* $v \in \mathrm{IR}$. *When* $v = 0$ *this is the traditional constant-elasticity demand with* $\eta = -\gamma$. *Note that now willingness to pay is unbounded as* Q *falls. By contrast,*

$$\lim_{p \to \infty} \eta(p) = -\gamma \cdot \lim_{p \to \infty} \frac{p}{v + p} = -\gamma,$$

hence the price elasticity of demand is bounded as p *rises (or* Q *falls). Again, this fact is of some importance below and, as will be seen, strongly suggests that this class of demand functions is not appropriate to analyze royalty stacking.*

Manufacturers To enter the industry and produce, each manufacturer must sink σ. Then it can produce each unit of the final good at constant long-run marginal cost c, Each manufacturer pays a royalty rate $\mathcal{R}$ per unit of output.

SEP holders There are m SEP holders. Each SEP reads on an invention that cannot be invented around and all inventions are complements. Each SEP holder incurs a licensing cost equal to c_u per unit and charges a per-unit royalty rate r_j. Thus $\mathcal{R} = \sum r_j$ is the aggregate royalty rate and mc_u the per unit aggregate licensing cost. To ensure that an equilibrium with production exists when there is no stacking and one licensee for all patents, we assume that $v - c - c_u > 0$.[11]

[10] Farbinger and Weyl (2012) call this the contant pass-through class of demand functions due to Bulow and Pfleiderer (1983).

[11] Note that we assume that inventions do not add any value. Assuming that inventions add no value is extreme, but many authors argue that stacking occurs in part because patents which add little or no value are used to hold up manufacturers. One can model valuable patents assuming that v is an increasing function of m.

Short-run competition Downstream competition is imperfect. In the short-run, symmetric equilibrium, each firm chooses its output q_i so that the equilibrium condition

$$P(Q) + \theta q_i P'(Q) = c + \mathcal{R}, \tag{3.3}$$

holds, where θ is the conduct or market power parameter. This nests most static oligopoly models: as is well known, when $\theta = 0$, there is perfect competition; $\theta = n$ yields the monopoly pricing; and $\theta = 1$ yields Cournot competition. Our aim in using this general structure is to examine the robustness of our results to alternative market conducts.

Timing The timing of the dynamic game, which is shown in Figure 3, is as follows. In the first stage n manufacturers sink σ. In the second stage, each SEP holder j simultaneously and independently chooses r_j taking the number of SEP holders, vector $\mathbf{r}_{-j}$ of royalty rates and industry structure as given. In the last stage each downstream manufacturer simultaneously sets q_i,given n and $\mathcal{R}$.

Our model is a standard exogenous sunk cost game with endogenous entry, where the conduct parameter θ indexes the intensity of price competition (see Sutton (1991)). Note that because royalties are set after manufacturers sink σ and each patent is pivotal, each SEP holder can hold up manufacturers. Moreover, because essential patents are complements and each SEP holder sets her royalty independently, royalties will stack in equilibrium.

In what follows we first solve the equilibrium entry game among manufacturers, taking the aggregate royalty rate as given (section 3.2). Next, in section 3.3, we compute the equilibrium royalty rate with holdup and royalty stacking, and examine their effect on the long-run performance of the industry.

3.2. Downstream equilibrium with endogenous entry

3.2.1. Competition in the product market

We begin with the last stage of the game. Then manufacturers take n and $\mathcal{R}$ as given and each solves

$$\max_{q_i} \left\{ q_i \left[P(Q) - (c + \mathcal{R}) \right] \right\}.$$

Standard manipulations of the first order condition (3.3) yields that in a symmetric equilibrium

$$p = \frac{\theta v + \gamma n (c + \mathcal{R})}{\theta + \gamma n}. \tag{3.4}$$

$$Q = S \left(\frac{\gamma n}{\theta + \gamma n} \right)^{\gamma} \cdot \left[v - (c + \mathcal{R}) \right]^{\gamma}; \tag{3.5}$$

Equation (3.4) shows the standard price-concentration relationship. Note that

$$\frac{\partial p}{\partial n} = -\frac{\theta \gamma}{(\theta + n\gamma)^2} \left[v - (c + \mathcal{R}) \right] < 0. \tag{3.6}$$

Prices fall as the number of firms increases and concentration falls (in a symmetric equilibrium $\frac{1}{n}$ is the Herfindahl index). Moreover, equations (3.4) and (3.5) show a basic relationship between aggregate royalties $\mathcal{R}$ and performance: with higher royalties, prices rise and quantities fall. Prices also fall as θ falls (the more intense price competition is) and with γ (the more elastic the demand for the good), ceteris paribus. Last, note that the pass through rate of royalties is

$$\frac{\partial p}{\partial \mathcal{R}} = \frac{\gamma n}{\theta + \gamma n} \leq 1. \tag{3.7}$$

As is well known, the rate of pass through is dollar-for dollar with perfect competition ($\theta = 0$) and constant marginal cost. With imperfect competition the rate of pass through is less than dollar for dollar for demand functions with $\gamma > 0$, but increases with the number of manufacturers.

In what follows margins are important. The standard price-cost equilibrium margin is

$$\mu \equiv p - (c + \mathcal{R}) = \frac{\theta}{\theta + \gamma n} \left[v - (c + \mathcal{R}) \right]. \tag{3.8}$$

Thus manufacturers appropriate part of the difference between marginal cost and willingness to pay. The Lerner margin is

$$\mathcal{L} \equiv \frac{p - (c + \mathcal{R})}{p} = \frac{\theta v - \theta (c + \mathcal{R})}{\theta v + \gamma n (c + \mathcal{R})}. \tag{3.9}$$

One may be tempted to study the effects of royalty stacking with this simple one-period model. Whether appropriate depends on your view of the magnitude of the royalty stacking-cum-holdup problem, however. If royalty stacking is one of many things going on in the industry, the short-run game is probably appropriate and the effects of higher aggregate royalties are rather straightforward: higher aggregate royalties increase the equilibrium price, reduce the total quantity sold and reduce manufacturer's margins and profits. By contrast, if royalty stacking is an overwhelming force in the industry, it is necessary to consider its effect on entry and structure. Next we model equilibrium entry.

3.2.2. Entry

In the long run, the zero-profit entry condition holds:

$$\mu^* \frac{Q^*}{n^*} \equiv \left[p^* - (c + \mathcal{R}) \right] \frac{Q^*}{n^*} = \sigma; \tag{3.10}$$

(we use a star * to denote long run equilibrium values). Condition (3.10) just says that margins times volume must cover sunk entry costs.

Let us now solve the entry game. When entering, firms anticipate the short-run game they will play. Hence, substituting (3.5) and (3.8) into (3.10) and rearranging yields

$$\left(\frac{\theta}{\theta + \gamma n^*} \right) \cdot \left(\frac{\gamma n^*}{\theta + \gamma n^*} \right)^{\gamma} \left[v - (c + \mathcal{R}) \right]^{\gamma + 1} \cdot \frac{S}{n^*} = \sigma.$$

Now rearrange this expression as

$$\frac{S}{\sigma} \cdot \theta \cdot \left[v - (c + \mathcal{R}) \right]^{\gamma + 1} = n^* \cdot (\theta + \gamma n^*) \cdot \left(\frac{\theta + \gamma n^*}{\gamma n^*} \right)^{\gamma} \equiv \phi(n^*; \theta, \gamma). \tag{3.11}$$

To appreciate the mechanics behind condition (3.11), it is useful to consider a linear demand ($\gamma = 1$) and Cournot competition ($\theta = 1$). Then the condition right hand side is

$$\phi(n^*) = (1 + n^*)^2,$$

which is increasing in n^*. Thus, with linear demand and Cournot competition anything that increases the size of the left-hand side also increases the equilibrium number of manufacturers, and the equilibrium number of firms is increasing in the ratio of market size S relative to the entry cost σ—the larger the market relative to the entry cost σ, the more manufacturers enter in equilibrium. Also, the number of firms is increasing in θ: the less intense is price competition, the more manufacturers there in equilibrium. Last, the number of firms is increasing in $v-(c+\mathcal{R})$—the more value added per unit, the more manufacturers enter. For the same reason, higher aggregate royalties $\mathcal{R}$ reduce the equilibrium number of firms, ceteris paribus.

Now some tedious Algebra shows that $\phi'(n^*) > 0$.[12] Hence the same relationships hold, regardless of γ and θ. We conclude that any parametric change that increases the left-hand side of (3.11) increases the number of firms and lead to a less concentrated industry in equilibrium; and any parametric change that decreases the left-hand side of (3.11) will decrease the number of firms and lead to a more concentrated industry.

3.2.3. Prices, quantities and concentration and their relation with royalties

We now return to the product market to derive the long-run relationship between aggregate royalties and observable market variables. We consider an exogenous increase of $\mathcal{R}$, the aggregate royalty rate. Totally differentiating both sides of (3.11) and rearranging yields

$$\frac{\partial n^*}{\partial \mathcal{R}} = -\frac{(\gamma+1)\frac{\theta S}{\sigma}\left[v-(c+\mathcal{R})\right]^{\gamma}}{\phi'(n^*)} < 0.$$

Result 3.1 (Royalties and concentration). *In the long run, higher aggregate royalties $\mathcal{R}$ reduce the equilibrium number of firms and increase concentration.*

To see how prices and quantities vary with and exogenous increase of $\mathcal{R}$, replace n^* into (3.4) and (3.13), totally differentiate with respect to $\mathcal{R}$ and rearrange. This yields

$$\frac{\partial p^*}{\partial \mathcal{R}} = \frac{\gamma n^*}{\theta + \gamma n^*} - \frac{\theta\gamma}{(\theta+\gamma n^*)^2}\left[v-(c+\mathcal{R})\right]\frac{\partial n^*}{\partial \mathcal{R}} > 0 \tag{3.12}$$

The impact of higher royalties on the long-run equilibrium price is the sum of two terms: first, the short run pass through rate $\frac{\gamma n^*}{\theta+\gamma n^*}$; second, higher aggregate royalties increase concentration, the industry moves along the price-concentration relationship and prices rise—the second term in (3.12). Note that with linear demand

[12] Indeed,

$$\frac{d\phi}{dn} = \frac{(\theta+n\gamma)^{\gamma}}{(n\gamma)^{\gamma}}\left(\left[\theta+\gamma(2n-\theta)\right]\right) > 0,$$

because, $\theta \le n$ with equality only when manufacturers price as a monopoly.

Similarly,

$$\frac{\partial Q^*}{\partial \mathcal{R}} = -\frac{Q^*}{v-(c+\mathcal{R})} + \frac{\theta}{n^*} Q^* \frac{\partial n^*}{\partial \mathcal{R}} < 0. \tag{3.13}$$

Thus the impact on the long-run equilibrium quantity is the sum of a short run effect, $\frac{Q^*}{v-(c+\mathcal{R})}$; and a long run effect—prices rise in a more concentrated industry and quantities fall even further. Hence:

Result 3.2 (Prices and quantities). *In the long run, higher aggregate royalties increase the equilibrium price, reduce the equilibrium quantity sold and concentrate the industry ceteris paribus.*

How general is Result 3.2? When the aggregate royalty rises exogenously the long run equilibrium price rises and the long-run equilibrium quantity falls with any plausible demand curve.

The increase in concentration is slightly less general, but still very likely. To see why, note that in equilibrium per-firm profits equal

$$\mu^* \frac{Q^*}{n^*} = [p^* - (c+\mathcal{R})] \frac{Q^*}{n^*} = \sigma.$$

Thus, concentration increases when the higher aggregate royalty reduces per firm profits with fixed n. In the model, this must occur because a higher aggregate royalty reduces the margin μ^* and the total quantity sold.

As is well known, however, for the family of demand curves (3.2) the short run rate of pass trough is greater than one—the short run equilibrium price μ rises more than dollar by dollar with a higher $\mathcal{R}$—and per firm profits may rise with a higher royalty. In that case a higher aggregate royalty would stimulate entry! Nevertheless, as we show in the Appendix, a necessary condition for this is that $\lim_{p\to\infty} \eta(p) = -\gamma < 1$ in (3.2). Nevertheless, with m SEP holders, an equilibrium with a finite royalty and some sales exists only if $-\gamma > m$, which is ruled out by $-\gamma < 1$. Thus, we ignore this case.

3.2.4. Margins and royalties

We now turn to margins. Simple differentiation yields that

$$\frac{\partial \mu^*}{d\mathcal{R}} = -\frac{\theta}{\theta+\gamma n^*} + \frac{\gamma\theta\,[v-(c+\mathcal{R})]}{(\theta+\gamma n^*)^2} \frac{\partial n^*}{\partial \mathcal{R}} \lesseqgtr 0$$

In the short run margins fall, because the rate of pass through is less than dollar by dollar. In the long run, however, the industry concentrates, and the equilibrium price rises, which tends to raise margins. Hence higher royalties have an ambiguous effect on long-run margins.

Similarly, the change in the Lerner margin of each manufacturer is

$$\begin{aligned}
\frac{\partial \mathcal{L}^*}{\partial \mathcal{R}} &= \frac{1}{p}\left(\frac{\partial \mu^*}{\partial \mathcal{R}} - \frac{\partial p^*}{\partial \mathcal{R}}\mathcal{L}^*\right) \\
&= \frac{1}{p}\left[(1-\mathcal{L}^*)\frac{\partial p^*}{\partial \mathcal{R}} - 1\right] \\
&= -\frac{\theta v(\theta+\gamma n^*)}{[\theta v+\gamma n^*(c+\mathcal{R})]^2} + \frac{\gamma\theta[v-(c+\mathcal{R})]}{(\theta v+\gamma n^*(c+\mathcal{R}))^2}(c+\mathcal{R})\left(-\frac{\partial n^*}{\partial \mathcal{R}}\right) \lesseqgtr 0.
\end{aligned}$$

Again, this is ambiguous (and a bit messy). Nevertheless, a sufficient condition for Lerner margins to fall is that the long-run rate of pass through is dollar-by-dollar or less. It can be shown that this will hold whenever production per firm, $\frac{Q^*}{n^*}$ does not fall as the industry concentrates.

3.3. Royalty stacking

3.3.1. The SEP holders' game

The SEP holder's decision When setting her royalty each upstream SEP holder takes m and downstream behavior as given, and solves

$$\max_{r} \left\{ (r - c_u) \times D(p) \right\}. \tag{3.14}$$

Call r_m^j SEP holder j's optimal individual royalty with m SEP holders and $\mathcal{R}_m$ the aggregate royalty. The first order condition is

$$(r_m^j - c_u) \times D'(p) \frac{\partial p}{\partial \mathcal{R}} + D(p) = 0.$$

Now in a symmetric equilibrium $r_m^j = r_m$ and $\mathcal{R}_m = m r_m$ Moreover,define $\epsilon_m = \frac{\partial p}{\partial \mathcal{R}} \frac{\mathcal{R}_m}{p}$ as the elasticity of downstream equilibrium prices with respect to the royalty rate. Then the first order condition can be rewritten as

$$\frac{r_m - c_u}{r_m} \times \frac{D'(p)}{D(p)} p \times \frac{\partial p}{\partial \mathcal{R}} \frac{\mathcal{R}_m}{p} \frac{1}{m} + 1 = 0$$

and, after some manipulations,

$$\frac{r_m - c_u}{r_m} = \frac{m}{\epsilon_m \eta}. \tag{3.15}$$

This is the well-known Cournot complements result (see Shapiro (2001)): each SEP holder "sees" the market demand of the final good and acts as a monopoly. The consequence is that m monopolists "stack" their royalties and they charge m times the Lerner margin that would be set by a monopoly licensing all patents.

Now it is useful to rewrite (3.15) as

$$r_m = \frac{\epsilon_m \eta}{\epsilon_m \eta - m} c_u. \tag{3.16}$$

Equation (3.16) might suggest that in equilibrium the individual royalty rate rises with the number of SEP holders. Nevertheless, when willingness to pay is bounded, the price elasticity of demand increases with p, so that r_m may fall with m, as we will see it is indeed the case.

Remark 2. *It can be shown that when willingness to pay is unbounded, the individual royalty rate grows with m and tends to a very large number very fast. To see why, note that when willingness to pay is unbounded, the price-elasticity of demand tends to a bound equal to $-\gamma$. Moreover, it can be shown that $\epsilon_m < 1$. Hence, as the number of SEP holders grows, $\epsilon_m \eta - m$ should tend to 0 fast,* *unless η is very large. To get a feel of how large is "large," note that the number of SEP holders is about 130 in 2013 in the mobile wireless industry. An equilibrium with production would require an almost infinitely elastic demand. Such is unlikely. Therefore, we ignore the family of demands (3.2), and relegate its analysis to the Appendix.*

Royalty stacking and the individual royalty We now return to the model. Some algebra yields that the individual royalty rate is

$$r_m = \frac{(v-c)+\gamma c_u}{m+\gamma}. \tag{3.17}$$

It is apparent that with bounded willingness to pay the equilibrium individual royalty is decreasing in m. Thus, as the number of SEP holders increases and royalty stacking worsens, one should observe lower individual royalties, ceteris paribus.

Result 3.3 (Royalty stacking and individual royalties). *With bounded willingness to pay the individual royalty rate is decreasing in the number of SEP holders.*

It might be somewhat surprising that individual royalty rates fall with the number of SEP holders—after all, holdup is supposed to yield excessive individual royalty rates. To discuss the economics, note that SEP holder's profit equals her margin times the aggregate quantity sold by manufacturers,

$$(r_j - c_u) \times D(p).$$

In equilibrium, she optimizes and

$$\left[D(p) + (r_m - c_u)D'(p)\frac{\partial p}{\partial \mathcal{R}}\right] dr_j = 0.$$

When a SEP holder marginally decreases her royalty in $dr_j < 0$, she loses $D(p)dr_j$; but as the downstream price falls in

$$\frac{\partial p}{\partial \mathcal{R}} dr_j$$

(the rate of pass through times the royalty change), her revenue increases by

$$(r_j - c_u)D'(p)\frac{\partial p}{\partial \mathcal{R}} dr_j.$$

In equilibrium, each SEP holder optimally balances this trade off, so that both effects are of equal size but opposite sign.

Now assume an additional SEP holder appears, charges r_m and everybody else keeps charging r_m. Then the equilibrium downstream price increases in $\frac{\partial p}{\partial \mathcal{R}} r_m$. Quantity obviously falls, and so does the loss of marginally decreasing the individual royalty rate. At the same time, depending on the sign of D'', the gain from slightly lowering the royalty rate may fall or rise. But if willingness to pay is bounded, it can be shown that the magnitude D' falls by less than D. Hence

$$D\left(p + \frac{\partial p}{\partial \mathcal{R}} r_m\right) + (r_m - c_u)D'\left(p + \frac{\partial p}{\partial \mathcal{R}} r_m\right)\frac{\partial p}{\partial \mathcal{R}} < 0.$$

and every SEP holder decreases her royalty rate as m increases.[13]

Royalty stacking and the aggregate royalty Consider now the aggregate royalty rate:

$$\mathcal{R}_m = mr_m = \frac{m}{m+\gamma}\left[(v-c)+\gamma c_u\right]; \tag{3.18}$$

as m increases and one royalty stacks upon the other, the aggregate royalty $\mathcal{R}$ increases with the number of SEP holders. Moreover, if $m \geq \frac{v-c}{c_u}$, the aggregate royalty rate exceeds the maximum willingness to pay and the downstream industry disappears.

Result 3.4 (Royalty stacking and the aggregate royalty). *In the long run, the aggregate royalty increases with the number of SEP holders and, if the number of SEP holders is large enough, the downstream industry disappears.*

3.3.2. Royalty stacking and SEP holders' margins

Some further Algebra yields that the equilibrium price-cost margin of each SEP holder is

$$r_m - c_u = \frac{1}{m+\gamma}\left[(v-c)+mc_u)\right],$$

while the corresponding equilibrium Lerner margin is

$$\mathcal{L}_m = \frac{r_m - c_u}{r_m} = \frac{(v-c)-mc_u}{v-c+c_u}.$$

It can be seen that both margins fall with m. Thus:

Result 3.5. *If willingness to pay is bounded, then SEP holders' Lerner margins fall as the number of SEP holders rises.*

3.3.3. Comparative statics

The results that we have obtained so far on royalty stacking hold "everything else" constant. Nevertheless, when we look below at the performance of the mobile wireless industry over the last two decades, "everything else" is not constant. In particular, the quality of mobile phones has

[13] Note that

$$\text{ms} \equiv P'Q = \frac{p}{\eta} = \frac{D}{D'}$$

is the marginal surplus function (see Appendix A). Then the equilibrium condition can be rewritten as

$$\left[1-(r_m-c_u)\frac{1}{\text{ms}(p)}\frac{\partial p}{\partial \mathcal{R}}\right]D(p)dr_j.$$

With bounded willingness to pay and constant rate of pass through, marginal surplus is decreasing as p rises. By contrast, for the family of demand functions such that willingness to pay is unbounded, $\text{ms}(p)$ is increasing (see the Appendix) and the optimal individual royalty rate increases with stacking. As we have already mentioned, however, such a family of functions has rather implausible implications.

increased, presumably raising willingness to pay v; and the manufacturing cost c has probably fallen. Nevertheless,

$$\frac{\partial \mathcal{R}_m}{\partial v} = -\frac{\partial \mathcal{R}_m}{\partial c} = \frac{m}{m+\gamma}.$$

Thus, when m is large, the aggregate royalty increases nearly dollar by dollar with willingness to pay; it also increases almost dollar by dollar when manufacturing costs fall.

Result 3.6. *When the number of SEP holders is large, the aggregate royalty changes almost dollar-by-dollar with v and c.*

An important implication of this result is that the effect of higher royalties wrought by stacking on prices cannot be undone by higher willingness to pay or lower manufacturing costs. Essentially, SEP holders acting with an objective function like (3.14) adjust their royalty rate in response to changes of v or c. Because the aggregate royalty rate does not depend on the market scale parameter S, neither do the implications on pricing change when market size exogenously increases, for example because the income elasticity is large and income grows very fast.

4. Evidence from the mobile wireless industry

How should one test whether there is royalty stacking when neither individual nor aggregate royalty rates are observable?[14] The theoretical literature on this issue has suggested that royalty stacking seriously harms the downstream manufacturing industry and may even threaten its existence – both predictions follow from our model as well. Thus royalty stacking is neither a marginal effect nor one among many other shocks affecting downstream manufacturing. On the contrary, when the number of SEP holders steadily grows over many years, royalty stacking is a protracted force which will, sooner or later, become the overwhelming determinant of industry performance, or so the literature and the model imply. Therefore, if royalty stacking is present and worsening, it should become apparent in the long-run evolution of observable equilibrium prices, quantities, structure, and margins.

In this section we examine prices, quantities, structure and innovation from the world mobile wireless manufacturing industry —firms that manufacture phones and tablets—between 1994 and 2013. We also examine the evolution of gross margins of the firms that participate in the 3GPP SSO, distinguishing between SEP holders and the rest of the firms.

4.1. Prices and quantities

For data on prices and quantities, we rely on data from Strategy Analytics – a large industry analysis firm that tracks different parts of the industry for market analysis. Table 1 shows data on the evolution of the mobile wireless manufacturing industry between 1994 and 2013. Columns 1 and 2 reproduce the data in Figure 1 and show the evolution of the number of SEP holders and SEPs (from ETSI). Column 3 shows the evolution of the average selling price (ASP) of a device in

[14] Although some estimates of aggregate royalties have been suggested, they vary widely.

2013 dollars, a wholesale average price which equals total world revenues from device sales divided by total units sold, which is not adjusted by quality and combines devices of successive generations; column 4 shows the evolution of the number of devices sold, in millions; and, last, column 5 shows total world sales of wireless devices in 2013 dollars (from Strategy Analytics).

Between 1994 and 2007 the number of SEP holders grew from 2 to 93 and the number of SEPs grew more than 380 times, from 139 to 54.146. Yet the average selling price of a device fell to one fifth its initial level, from \$853 in 1994 to \$173 in 2007, or −11.5% per year on average. From then on the number of SEP holders grew further to 130 in 2013 and the number of SEPs almost tripled to 143.442 in 2013. The average selling price fell an additional 20% between 2007 and 2010, but then increased during 2012 and 2013. Is this evidence that royalty stacking is finally biting?

Table 2 shows the composition of device sales by technological generation between 2007 and 2013. As can be seen from panel A ("Share of devices"), in 2007 more than one-third of devices sold were of the, by then mature, 2.5G generation and almost one-fourth were 2.75G Edge phones. By contrast, only 18.7% of sold devices were 3G or more. Six years later, in 2013, two-thirds of all devices sold were of generation 3G or more. As panel B ("Price (ASP) \$ 2013") shows, the average price of a device of a later generation is higher. Thus the slowdown in the rate of price fall in Table 2 only reflects the diffusion of higher-generation devices and the rather fast demise of earlier generations. More important, as panel C shows ("Price (ASP) 2007 = 100"), since 2007 the average price of a device of the same generation has fallen between 52% and 84% (or between 12,2% and 30,5% per year). Thus, we find no evidence of rising prices due to royalty stacking (or any other cause).

As prices have fallen, device sales have increased. As column 4 in Table 1 shows, in 1994 the one manufacturer (Ericsson) sold 29 million devices. In 2007, by contrast, 44 manufacturers sold 1.1 billion devices, a 39-fold increase or 26,3% per year. Since 2007, device sales grew further, to almost 1.8 billion in 2011, or 10% per year. Since then, the number of devices sold has not grown, but this masks a substantial change in composition. As can be deduced from panel A of Table 2, sales of 3G devices have fallen from 314 million in 2010 to 166 million in 2013; by contrast, sales of 3.5 and 4G devices have grown from 330 million in 2010 to 1,031 million in 2013.

Column 5 in Table 1shows industry revenues, which increased more than eight times between 1994 and 2007 and about 50% since then. Of course, revenue growth is just the result of growing sales, which more than compensate for price falls. But in any case, it just confirms that as the number of SEP holders has increased, the industry expanded, and fast.

4.2. Market structure

Royalty stacking theory also predicts that the industry will concentrate as the number of SEP holders rises. Figure 4 shows the number of phone manufacturers between 1992 and 2013 and average sales per manufacturer. Note that the number of firms steadily grew from one in 1994 (Ericsson) to 20 in 2002, then jumped to 40 in 2006 and then stabilized around that number. With the exception of the initial years of the industry, average sales per firm have hovered around \$5-7 billion. This suggests that as industry size grows, new manufacturers enter.[15]

The number of manufacturers might not depict of concentration and structure accurately, because firms have different sizes. We have data on the number of devices sold by each manufacturer since 2001 and Figure 5 plots the number of equivalent device manufacturers[16]. Note that it hovers around six until 2004, then falls to about five in 2008 and then steadily grows up to about nine in 2013. Hence, concentration fell, despite of the fact that sales per equivalent manufacturer more or less doubled, from about \$20 billion between 2001 and 2003 to about \$40 billion since then. Again, we fail to find evidence consistent with royalty stacking.

4.3. Margins

4.3.1. The evolution of gross margins

As we saw in the previous section, with bounded willingness to pay SEP holders' Lerner margins should fall with royalty stacking. Manufacturers, by contrast, may price to obtain higher or lower long-run Lerner margins, but in any case there should be a systematic effect of stacking.

To examine whether there is some trace of royalty stacking in margins, we collected financial data on the universe of firms that participated in the development of the global third and fourth generation wireless cellular standards—over 300 firms— between 1994 and 2013 and for each computed gross margins year by year.[17,18] We coded each firm by the number of SEPs it can assert and separated the sample between firms who held at least one SEP and firms who hold no SEP (until a firm declares its first SEP, it is classified as non-SEP holder).

Figure 6 shows gross margins of SEP holders and the rest of participants in 3GPP for which we could find financial data (right axis). The average gross margin of SEP holders hovers between 30% and 35%, but shows no downward trend. The average gross margin of non-SEP holders is higher and fluctuates more, but there is no sustained, long-run trend.

Figure 7 repeats the exercise, but only with device manufacturers. Now the average gross margin of SEP holders hovers around 30% , but shows no trend. And again, the average gross margin of non-SEP holders is higher and fluctuates more, but there is no sustained, long-run trend.

We checked the robustness of these trends by classifying as "SEP holder" a firm with at least 100 SEPs; by distinguishing between members of the SSO and attendees; by trying with an alternative financial database with coverage since 2004, but with data from more firms; and by using weighted averages. While levels may vary a bit, no trend appears.

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[15] See the Appendix for data description.

[16] Let $\mathcal{H}$ be the Herfindahl index. The number of equivalent firms is equal to $\frac{1}{\mathcal{H}}$, or the number of firms of equal market shares that would produce the same Herfindahl index. See Adelman (1969).

[17] Gross margin is calculated as the ratio of revenues less the cost of goods sold (production or acquisition costs) to sales. It is an imperfect measure of Lerner margins because it includes fixed, average costs and Ricardian rent. An additional limitation might be that some of the cost items included in production or acquisition costs are not part of short-run marginal costs. This is less importantheree because we track the long-run performance of the industry. Then long-run marginal cost, which includes costs which are fixed in the short run, are relevant for pricing decisions. See Boiteaux (1960).

[18] Gross margins are obtained from Thomson One. Each year each firm's gross profit is divided by total revenues as reported on the firm's financial statements.

We checked the robustness of these trends by classifying as "SEP holder" a firm with at least 100 SEPs; by distinguishing between members of the SSO and attendees; by trying with an alternative financial database with coverage since 2004, but with data from more firms; and by using weighted averages. While levels may vary a bit, no trend appears.

4.3.2. Regression analysis

Many other factors affect firms' gross margins. To control for them we also run the following regression:

$$
\begin{aligned}
\text{gross margins} \;=\; & \alpha_0 + \alpha_1(\text{cumulative \# of SEP holders}) + \alpha_2(\text{SEP holder dummy}) \\
& + \alpha_3(\text{SEP holder dummy } \times \text{cumulative \# of SEP holders}) \\
& + \beta_1(\text{R\&D intensity}) + \beta_2(\text{total \# of employees}) + \beta_3(\text{capital stock}) \\
& + \gamma_1(\text{component f.e.}) + \gamma_2(\text{device f.e.}) + \gamma_3(\text{other f.e.}) \\
& + \delta_1(\text{country f.e.}) \\
& + \xi_1(\text{component f.e } \times \text{\# of SEP holders}) + \xi_2(\text{ device f.e. } \times \text{\# of SEP holders}) \\
& + \xi_3(\text{other f.e. } \times \text{\# of SEP holders})
\end{aligned}
$$

The first coefficient, α_1, measures the effect on margins of the cumulative number of SEP holders. The second coefficient, α_2, measures whether SEP holders have systematically different margins. The third coefficient measures whether the number of SEP holders has a systematic effect on SEP holder margins. Recall that the model predicts that $\alpha_3 < 0$: as the number of SEP holder rises, each individual SEP holder prices less aggressively and gross margins should fall.

We also control for other determinants of gross margins. First, firm-specific characteristics: R&D intensity (β_1), the number of employees (β_2) and the size of the capital stock (β_3). Second, the firm's place in the value chain (see Figure 2): the base category is infrastructure manufacturer and we add dummies for a component manufacturer (γ_1), a device manufacturer (γ_2) and other non-manufacturer (γ_3). Third, a fixed effect controlling for the country where the firm's headquarter is located (δ_1). Last, we add interaction terms between he firm's place in the value chain and the number of SEP holders (ξ_i).

Column 6 in Table 3 shows the results. Note first that the effect on gross margins of additional SEP holders is insignificant and, in any case small: increasing the number of SEP holders from 0 to 100 would increase gross margins in 2,5 percentage points. Second, SEP holders have smaller gross margins ($\widehat{\alpha}_2 = 12.14$). Third, the interaction coefficient between the SEP holder dummy and the cumulative number of SEP holders is significant but positive. If the number of SEP holders increases from 0 to 100, SEP holders' gross margins increase by $6,6$ percentage points. While the 95% confidence interval is rather wide (if the number of SEP holders increases from 0 to 100, the size of the effect ranges from -1 percentage points to $14,6$ percentage points), the direction of the change is the opposite to that predicted by the royalty stacking hypothesis.

Like SEP holders, device manufacturers' gross margins seem to be systematically lower than the baseline group (infrastructure manufacturers). Nevertheless, the number of SEP holders does not seem to affect them: the interaction coefficient is statistically insignificant and, in any case, it is small: the point-estimate of the effect on gross margins of increasing the number of SEP holders from 0 to 100 is 2,59 percentage points.

Table 4 repeats the estimation, but now the explanatory variable is the number of SEPs (in thousands). With a few exceptions, the point estimates are similar. Again, the effect on gross margins of SEPs is positive but insignificant and small: increasing the number of SEPs from 0 to 100.000 would increase gross margins by 2,4 percentage points. And the interaction coefficient between the SEP holder dummy and the cumulative number of SEP holders is statistically insignificant and positive.

All in all, we do not find evidence consistent with the royalty stacking hypothesis.

5. Conclusion

In complex technologies such as the high-tech industry, where most products sold to end users incorporate many patented inputs, some authors have used the Cournot-complements logic to suggest that royalty rates might be too high. Market-driven mechanisms, such as cross-licensing and reputation effects might not suffice to prevent royalty stacking. Indeed,

A number of proposals have been put forth to solve the perceived problem, all aimed at lowering royalty rates charged by patent holders. These include patent pool rates (Lerner and Tirole (2002)), valuation of technologies before they are adopted as the standard (Swanson and Baumol (2005), Skitol (2005)) or capping royalty rates based on the incremental value of the patents over their next best alternatives (Farrell et al (2007)).

In this paper, we developed an equilibrium model that describes the mechanisms with which royalty stacking may occur and derived the observable implications of the hypothesis. According to the literature and the model, when the number of SEP holders steadily grows over many years, royalty stacking is a protracted force which will, sooner or later, become the overwhelming determinant of industry performance. We looked for evidence of royalty stacking in the world mobile wireless industry, where the number of SEP holders protractedly grew from 2 in 1994 to 130 in 2013, and failed to find it. Contrary to the implications of the royalty stacking hypothesis, prices have been falling, volumes have been rising, market concentration has been falling, and margins have stayed more-or-less constant for firms participating in the industry.

Perhaps the lack of evidence for the royalty stacking hypothesis can be explained by self interest: SEP holders and manufacturers lose with royalty stacking; they have an incentive to find means to prevent it.

Appendix

A. Some technical results

A.1. Royalty stacking with unbounded willingness to pay

A.1.1. Demand

Consider demand function (3.2) in the text

$$Q = S(v + p)^{\gamma},$$

with $\gamma < 0$ and $v \in \mathrm{IR}$. When $v < 0$ the quantity demanded approaches infinity as $p \to -v$ and approaches 0 as $p \to \infty$. Thus willingness to pay for the first unit is very high. Now the price elasticity is

$$\eta(p) = -\gamma \frac{p}{v + p}.$$

When $v > 0$, $\eta(0) = 0$, $\eta' > 0$ and $\lim_{p\to\infty} \eta(p) = -\gamma$. On the other hand, if $v < 0$, p is bounded below by $-v$, $\lim_{p\to-v} \eta(p) = \infty$, $\eta'(p) < 0$ and $\lim_{p\to\infty} \eta(p) = -\gamma$. Last, when $v = 0$ this yields the constant-elasticity demand with $\eta = -\gamma$.

A.1.2. Downstream equilibrium

Again, we begin with the last stage of the game. Manufacturers take n and $\mathcal{R}$ as given and each solves

$$\max_{q_i} \left\{ q_i \left[P(Q) - (c + \mathcal{R}) \right] \right\}.$$

Standard manipulations of the first order condition (3.3) yields that in a symmetric equilibrium

$$Q = S \left(\frac{n\gamma}{\theta + n\gamma} \right)^{\gamma} (v + c + \mathcal{R})^{\gamma} \tag{A.1}$$

and

$$p = \frac{-\theta v + n\gamma(c + \mathcal{R})}{\theta + n\gamma}. \tag{A.2}$$

Note that the rate of pass through is

$$\frac{\partial p}{\partial \mathcal{R}} = \frac{n\gamma}{\theta + n\gamma}.$$

Consider first $v \geq 0$. Because $n\gamma < 0$, a necessary condition for existence of an equilibrium with production is $\theta + n\gamma < 0$; otherwise $\frac{n\gamma}{\theta+n\gamma} < 0$ and $Q < 0$ in (3.7).[19] Now if $v < 0$ but $v + c + \mathcal{R} \geq 0$, again $\theta + n\gamma < 0$ is necessary for existence.

Last, if $v < 0$ but $v + c + \mathcal{R} < 0$, then $n\gamma \cdot (v + c + \mathcal{R}) > 0$ and $\theta + n\gamma > 0$ is necessary for existence of an equilibrium with production. Nevertheless, then $\frac{\partial p}{\partial \mathcal{R}} = \frac{\partial p}{\partial c} = \frac{n\gamma}{\theta+n\gamma} < 0$: higher costs *reduce* the equilibrium price—the rate of pass through is negative—, a rather implausible consequence. For this reason, we ignore this case and henceforth assume that $v + c + \mathcal{R} > 0$ and $\theta + n\gamma < 0$.

A.1.3. Royalty stacking

Assume that demand is of the form (3.2) and let each SEP holder choose r to

$$\max_{r} \left\{ (r - c_u) \times \frac{S}{(v + p)^{-\gamma}} \right\}.$$

Some algebra yields that

$$r_m = \frac{v - c - \gamma c_u}{(-\gamma - m)}$$

[19] Note that with $\theta = n$ (monopoly conjectures) this condition reduces to $1 + \gamma < 0$; that is, the upper bound of the elasticity must be greater than one.

and

$$\mathcal{R}_m = \frac{m}{(-\gamma - m)}(v - c - \gamma c_u),$$

with $m + \gamma < 0$. Thus for fixed γ,

$$\lim_{m \to -\gamma} r_m = \lim_{m \to -\gamma} \mathcal{R}_m = \infty.$$

Now the elasticity tends to $-\gamma$ as p rises. It follows that unless $-\gamma$ is very large, an equilibrium with production does not exist. For example, in 2013 there were 130 different SEP holders. Hence $-\gamma < 130$ implies that the industry should have disappeared!

A.1.4. Can royalty stacking increase downstream profits?

One of the predictions of the model in section 3 is that concentration rises with the aggregate royalty. The economics at work is that with fixed n, higher royalties reduce industry and per-firm profits

$$[p - (c + \mathcal{R})] \frac{Q}{n},$$

which now are not enough to pay for the entry cost σ unless concentration rises. Nevertheless, it is well known that oligopolists' profits may rise when costs increase (see, for example, Seade (1985) and Kimmel (1992)). If profits increase with $\mathcal{R}$ and fixed n then concentration would fall with higher royalties.

Under which circumstances will profits rise? With demand function (3.2) total profits are

$$-\frac{\theta[v + (c + \mathcal{R})]}{\theta + n\gamma} S(v + p)^{\gamma}.$$

With fixed n

$$\frac{\partial \pi}{\partial \mathcal{R}} \propto (v + p)^{\gamma} + [v + (c + \mathcal{R})](v + p)^{\gamma - 1} \frac{\partial p}{\partial \mathcal{R}}.$$

Now recall that $\frac{\partial p}{\partial \mathcal{R}} = \frac{n\gamma}{\theta + n\gamma}$. Hence

$$\frac{\partial \pi}{\partial \mathcal{R}} \propto 1 + \frac{v + (c + \mathcal{R})}{(v + p)}^{\gamma - 1} \frac{n\gamma}{\theta + n\gamma}.$$

Substituting (A.2) into this expression, simplifying and rearranging yields

$$\frac{\partial \pi}{\partial \mathcal{R}} \propto 1 + \gamma.$$

Hence profits rise with $\mathcal{R}$ only if $-\gamma \in [0, 1)$. but then an equilibrium with production does not exist. Hence, rising profits are inconsistent with royalty stacking; concentration must increase with $\mathcal{R}$ if an equilibrium with royalty stacking and production exists.

A.1.5. Royalty stacking and increasing SEP margins

In the text we obtained that as m increases, SEP holders price less aggressively. Thus r_m, μ_m and $\mathcal{L}_m$ are decreasing in m. These results reverse if willingness to pay is unbounded as $Q \to 0$. Then r_m, μ_m and $\mathcal{L}_m$ are increasing in m.

To see this, recall that

$$r_m = \frac{v - c - \gamma c_u}{(-\gamma - m)},$$

$$\mu_m \equiv r_m - c_u = \frac{v + c + m c_u}{(-\gamma - m)}$$

and

$$\mathcal{L}_m \equiv \frac{r_m - c_u}{r_m} = \frac{v + c + m c_u}{v + c - \gamma c_u}.$$

Hence

$$\frac{\partial r_m}{\partial m} = \frac{v - c - \gamma c_u}{(-\gamma - m)^2} > 0;$$

$$\frac{\partial r_m}{\partial m} = \frac{c_u}{(-\gamma - m)} + \frac{v + c + m c_u}{(-\gamma - m)^2} > 0,$$

and

$$\frac{\partial \mathcal{L}_m}{\partial m} = \frac{c_u}{v + c - \gamma c_u} > 0.$$

Nevertheless, increasing individual royalties and margins require $m < -\gamma$ which, we have seen, is unlikely if an equilibrium with royalty stacking and production exists.

A.2. The marginal surplus function

In the text use the marginal surplus function

$$\text{ms} \equiv -P'Q = \frac{p}{\eta} = -\frac{D}{D'};$$

and its derivative with respect to p:

$$\frac{d\text{ms}}{dp}(p) = \frac{1}{\eta(p)}\left[1 - \text{ms}(p)\cdot\eta'(p)\right] = \begin{cases} -\frac{1}{\gamma} & < 0 \quad \gamma > 0, b = 1 \text{ and } v > 0. \\ 0 & \quad\quad \gamma, v \to \infty, \frac{\gamma}{v} \text{ constant;} \\ -\frac{1}{\gamma} & > 0 \quad \gamma < 0, b = -1 \text{ and } v \in \text{IR}. \end{cases}.$$

Note that marginal surplus falls with price if $\gamma > 0$; is constant with exponential demand; and increases with price if $\gamma < 0$.

It is also useful to define the inverse elasticity of the marginal surplus function:

$$\frac{1}{\epsilon_{\text{ms}}} \equiv \frac{Q\cdot\text{ms}'}{\text{ms}} = -\frac{1}{\eta^2}\left[1 + \frac{d\eta}{dQ}Q\right] = \begin{cases} \frac{1}{\gamma} & > 0 \quad \gamma > 0, b = 1 \text{ and } v > 0. \\ 0 & \quad\quad \gamma, v \to \infty, \frac{\gamma}{v} \text{ constant;} \\ \frac{1}{\gamma} & < 0 \quad \gamma < 0, b = -1 \text{ and } v \in \text{IR}. \end{cases}.$$

In what follows the rate of pass through, $\frac{dP}{d(c+\mathcal{R})}$, is of some importance. Within the class of functions as in (3.1), the rate of pass through is constant when marginal cost is flat and the conduct parameter θ is constant[20]. To see this, totally differentiate both sides of (3.3), which yields

$$d(c+\mathcal{R}) = \left(1 - \frac{\theta}{n}\text{ms}'\frac{dQ}{dp}\right)dP = \left(1 + \frac{\theta}{n\epsilon_{\text{ms}}}\right),$$

Hence

$$\frac{dP}{d(c+\mathcal{R})} = \frac{1}{1 + \frac{\theta}{n\epsilon_{\text{ms}}}}$$

and

$$\frac{dP}{d(c+\mathcal{R})} = \begin{cases} \frac{n\gamma}{n\gamma+\theta} & \leq 1 \quad \gamma > 0, b = 1 \text{ and } v > 0. \\ 1 & \quad\quad \gamma, v \to \infty, \frac{\gamma}{v} \text{ constant;} \\ \frac{n\gamma}{n\gamma+\theta} & \geq 1 \quad \gamma < 0, b = -1 \text{ and } v \in \text{IR}. \end{cases}.$$

B. Data description

B.1. SEPs and SEP owners

We use patent declaration data collected from the European Telecommunications Standards Institute (ETSI), spanning 1994-2013, for 3G and 4G wireless cellular standards. The IPR policies of the SSOs forming 3GPP require firms to declare their patents that may be potentially essential to the 3GPP standards (often termed as standards essential patents (SEPs)), and most firms declare these patents to ETSI, the primary SSO who manages 3GPP.

We perform several clean-up and correction steps on the ETSI patent declaration data, such as: (i) identifying missing patent numbers from some patent declarations; (ii) rolling-up firm names to parent companies, that is, names of declaring entities that are subsidiaries or acquired by a parent firm are listed under the name of the parent firm; (iii) identifying all the patents in the same "family" of those declared. In other words, a firm may declare a patent in one jurisdiction (e.g. a US patent), and then obtain patents for the same invention in other jurisdictions (e.g.: a patent in the European Union, JP patent etc.). Per ETSI's IPR policy, all these patents—called a patent family—are

[20] See Bulow and Pleiderer (1983) and Weyl and Farbinger (2013).

considered potentially essential. Therefore, for all the patents in ETSI declaration database, we expand the set to include the related patent family members in the data-set as well.

The final patent declaration data-set contains the list of patents declared to ETSI and the family members of patents declared to ETSI, along with the firm name and the date of declaration.

B.2. 3GPP firm level data

The data-set for the margin analysis and the regression analysis study is based on firms that participated in 3GPP. To conduct the analysis we rely on a comprehensive data-set on 3GPP built by Baron and Gupta (2015). This includes a historical list of 3GPP members, i.e., the names of organizations that are or were members of 3GPP during the development of wireless cellular standards as well as firms that attended 3GPP meetings from 2000-2014. There is a difference between membership and meeting attendance. Firms that are members have voting rights towards what may or may not enter the standard, but any firm can attend the meetings and follow the progress of the standards being developed. Firms often attend the meetings to develop the human capital required to understand the complex technologies that their products need to implement, rather than to directly contribute their technologies to the standards or participate in the voting process. Therefore, some firms become voluntary members of 3GPP but do not attend any meetings, while some firms do not become members and attend the meetings and thereby participate in the standard setting process. For our purposes, in order to capture the universe of firms that may be generating or implementing the standardized technology, we are interested in both membership and attendance records.

The historical list of 3GPP member firms is available for 2000, 2001, 2013, and 2014, and the firms that attended 3GPP meetings between 2000 and 2014 was obtained from the attendance records of over 825 meetings of 3GPP "working group" meetings, where the different aspects of standards are developed. We then merge these membership and attendance records, remove duplicates, clean for firm names, and rolling-up subsidiaries and acquisitions to parent companies (see Baron and Gupta (2015) for further details). Based on this exercise, we identify 765 unique organizations that were members or attendees of 3GPP. Of these 618 are for-profit organizations, while others were educational institutions, research institutions, other SSOs, or government agencies (e.g. FCC, British Telecom Administration, etc.). Because this study is interested in profit margins of firms, these organizations are not included in the analysis as they do not report financial information or do not have revenues, profits, etc.

We collected financial information of firms from ThomsonOne, which lists financial information for public firms from 1994-2014. We identified financial information 223 firms in ThomsonOne from 1994-2014. For each firm, we also identified whether or not a firm is a SEP holder. Any firm with at least one declared SEP is a SEP holder from the date of its first patent declaration to ETSI. In other words, if a firm first declared an SEP in 2005, it would be considered a SEP holder from 2005 onwards only.

For each firm, we also identified where it lies in the mobile wireless value chain, i.e., whether these firms are component manufacturers, consumer devices manufacturers, infrastructure manufacturers, or other non-manufacturing firms. This categorization is done based on SIC codes, information from Onesource, and by interviewing a number of engineers who attended standards meetings. For example: (i) component manufacturers manufacture semiconductor chips, application processors, memory cards, sensors, screens, or cameras, that form component inputs of mobile devices or network base-stations; (ii) device manufacturers package components into mobile devices such as smartphone and tablets; (iii) infrastructure manufacturers manufacture routers, cellular base stations, servers, etc., through which wireless communication is made possible; (iv) the "other" category includes firms such as network operators who maintain and manage the networks and user subscriptions.

B.3. Market data

We collected information on the prices of devices, the number of devices sold, the type of devices sold and the market share of firms from 1994-2013.

Two data-sources were used to collect this information. Data published by Strategy Analytics was used for the number of devices sold, the average selling price (ASP) of a phone and volume of devices sold from 1994-2013. Strategy Analytics is an industry analyst firm that provides the non-quality-adjusted (retail) prices of devices by year. In addition they publish data on the volume of devices sold by year by firm which is used to calculate market share by company. In addition to implications for volumes and price, the royalty stacking theory has implications related to the diversity of products and product brands offered to consumers. Information on all devices released from 1994-2013 was collected from www.gsmarena.com. This is a publicly available data source which provides information on device manufacturers, its specification and the date the product was released.

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Figure 1
Number of SEPs and SEP holders
(1994-2013)

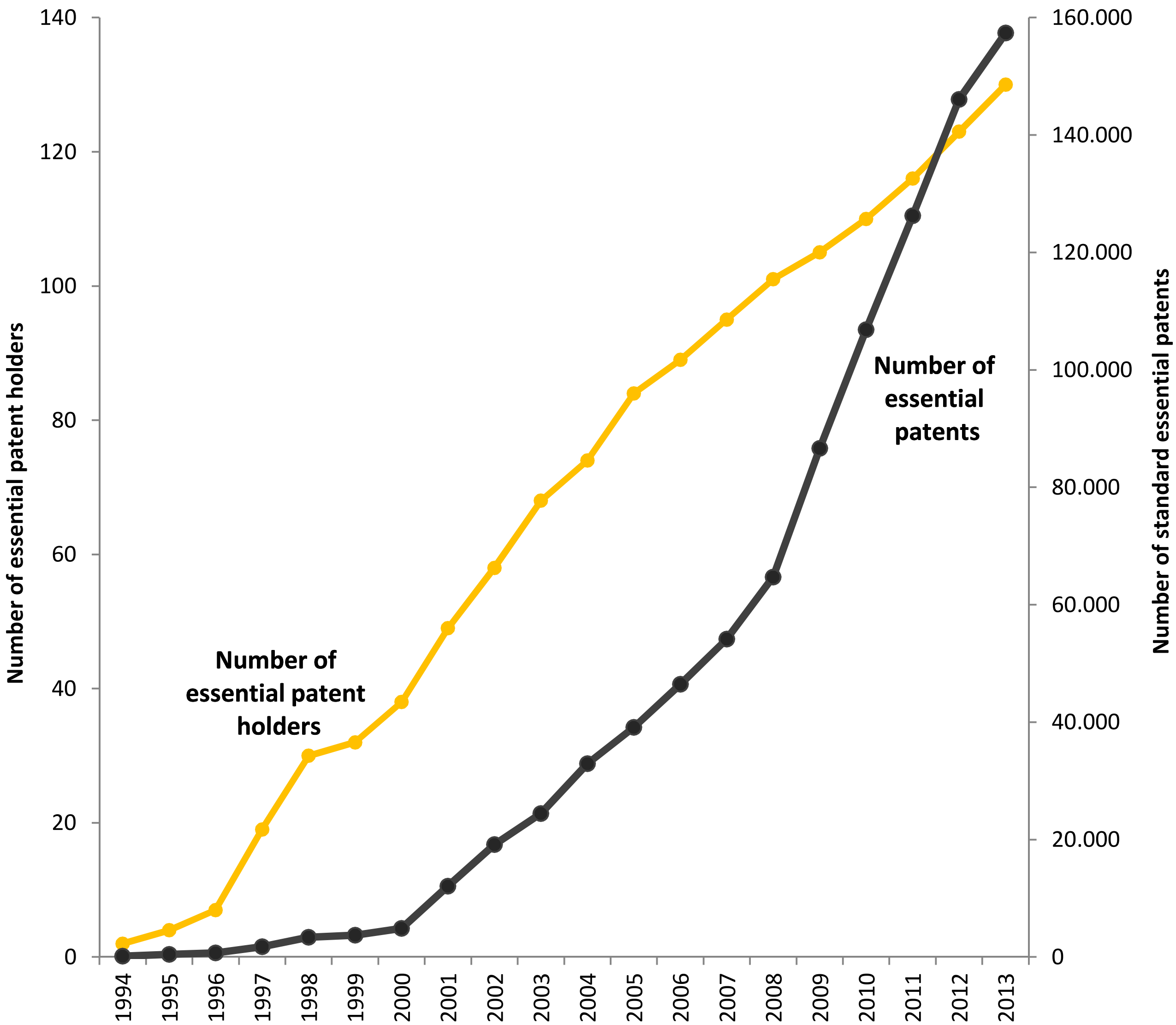


Figure 2

The mobile wireless industry value-chain

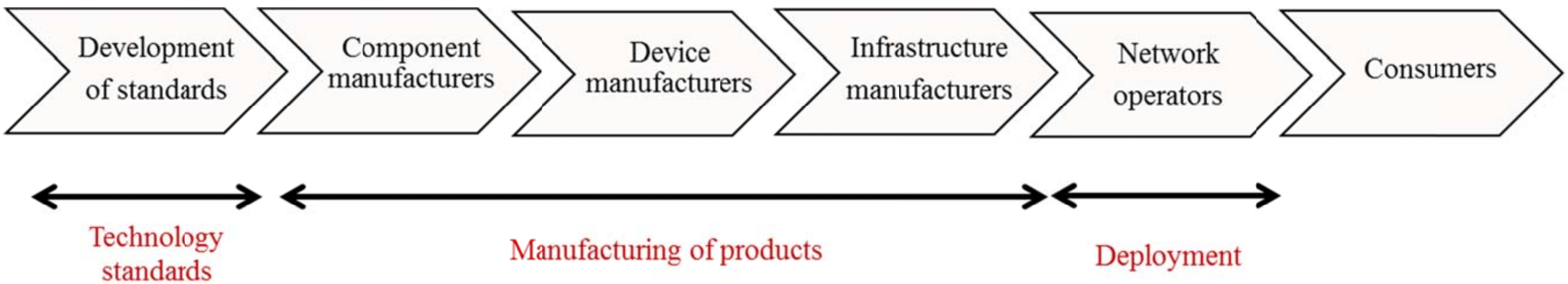


Figure 3: the royalty stacking game

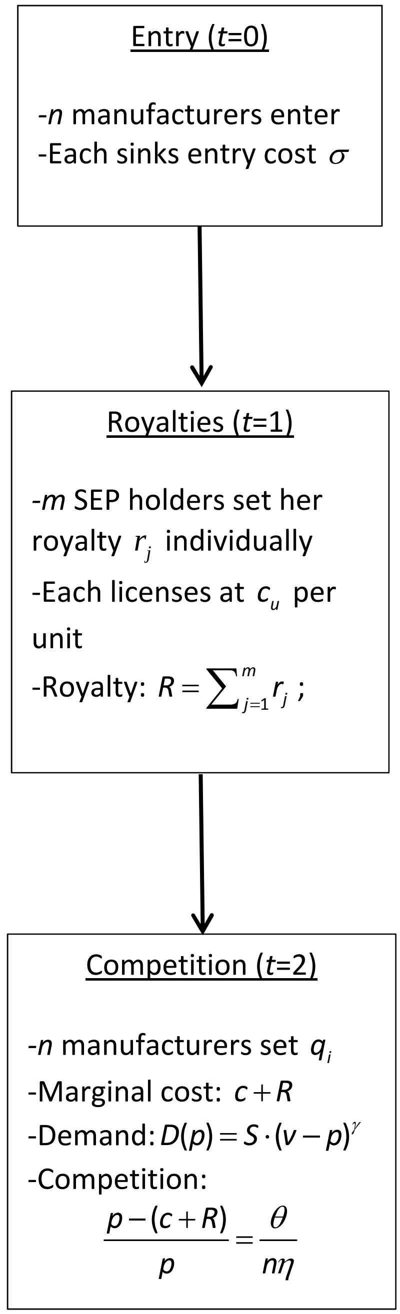
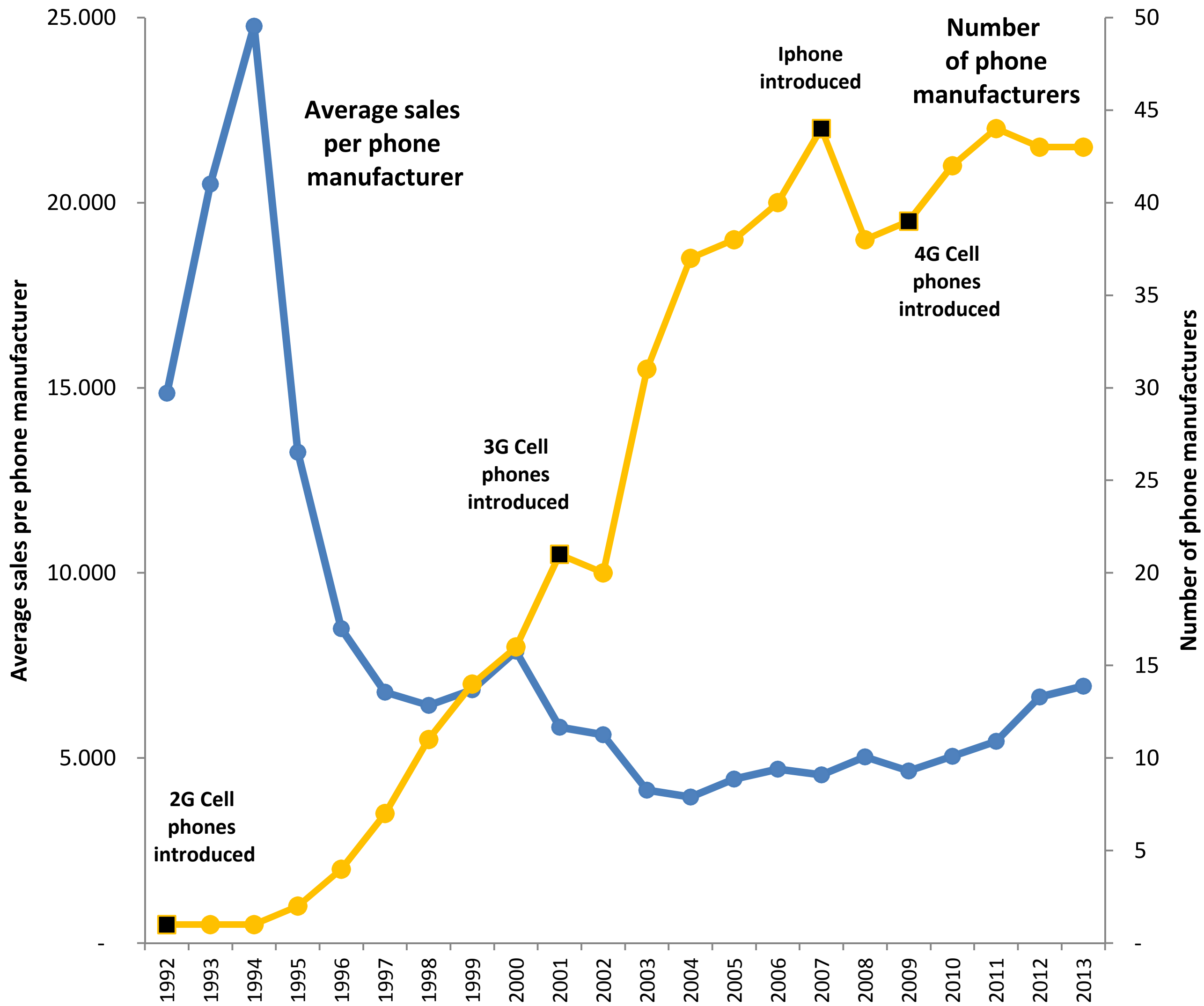
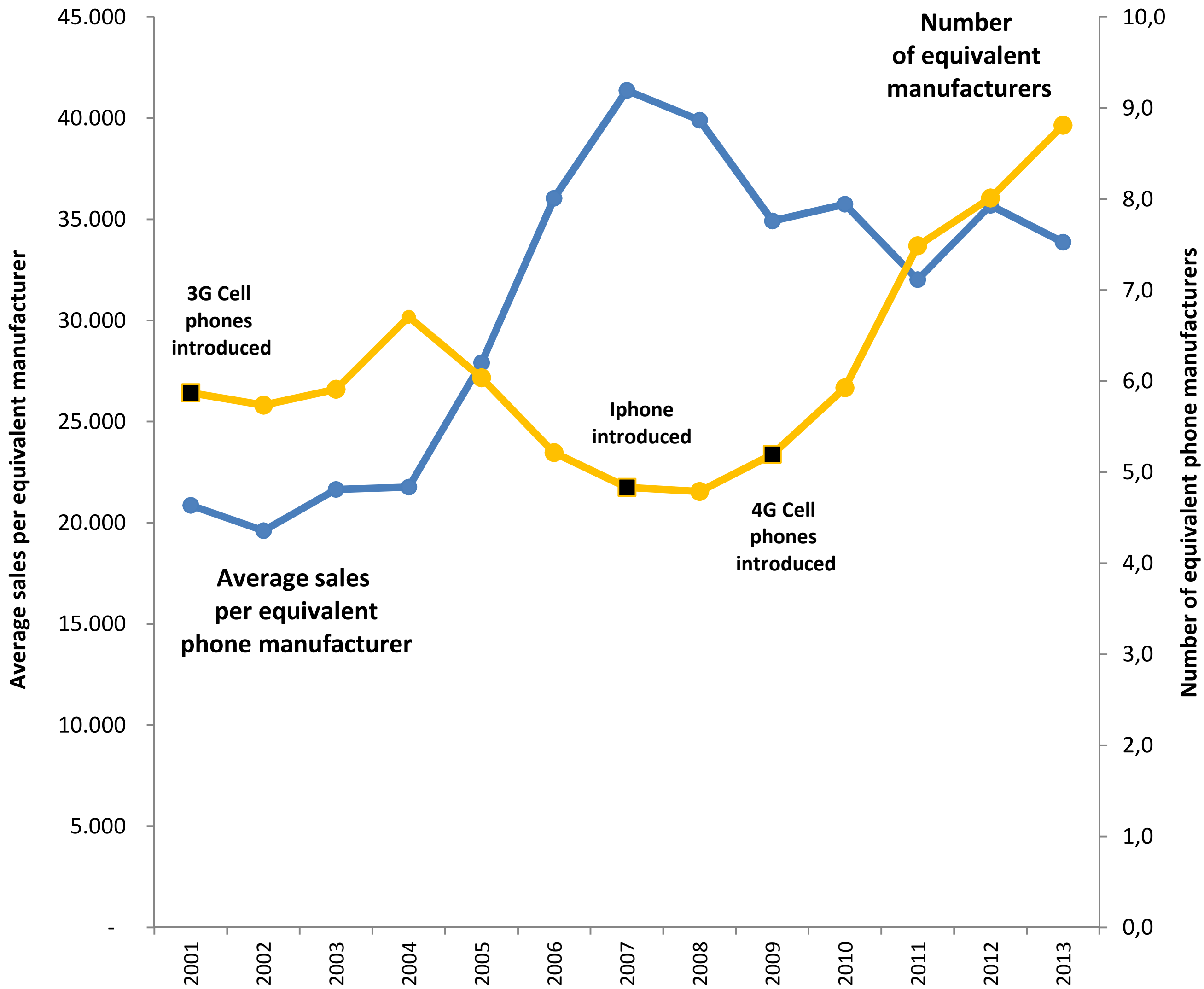


Figure 4
Number of of phone manufacturers and average sales per firm (1992-2013, millions of 2013 $)



This graph shows the evolution of average sales per smartphone manufacturer. Until 2004 the number of firms grew substantially; after 2004, the number stabilized between 40 and 45. Average sales per manufacturer stabilize between 5-7 billion a year ---the number of firms is roughly proportional to market size.

Figure 5
Number of equivalent phone manufacturers and average sales per equivalent firm (2001-2013, millions of 2013 $)



This graph shows the evolution of average sales per smartphone manufacturer. Until 2004 the number of firms grew substantially; after 2004, the number stabilized between 40 and 45. Average sales per manufacturer stabilize between 5-7 billion a year ---the number of firms is roughly proportional to market size.

Figure 6
Average gross margins,
SEP holders (≥ 1 SEP) and rest
(1994-2013)

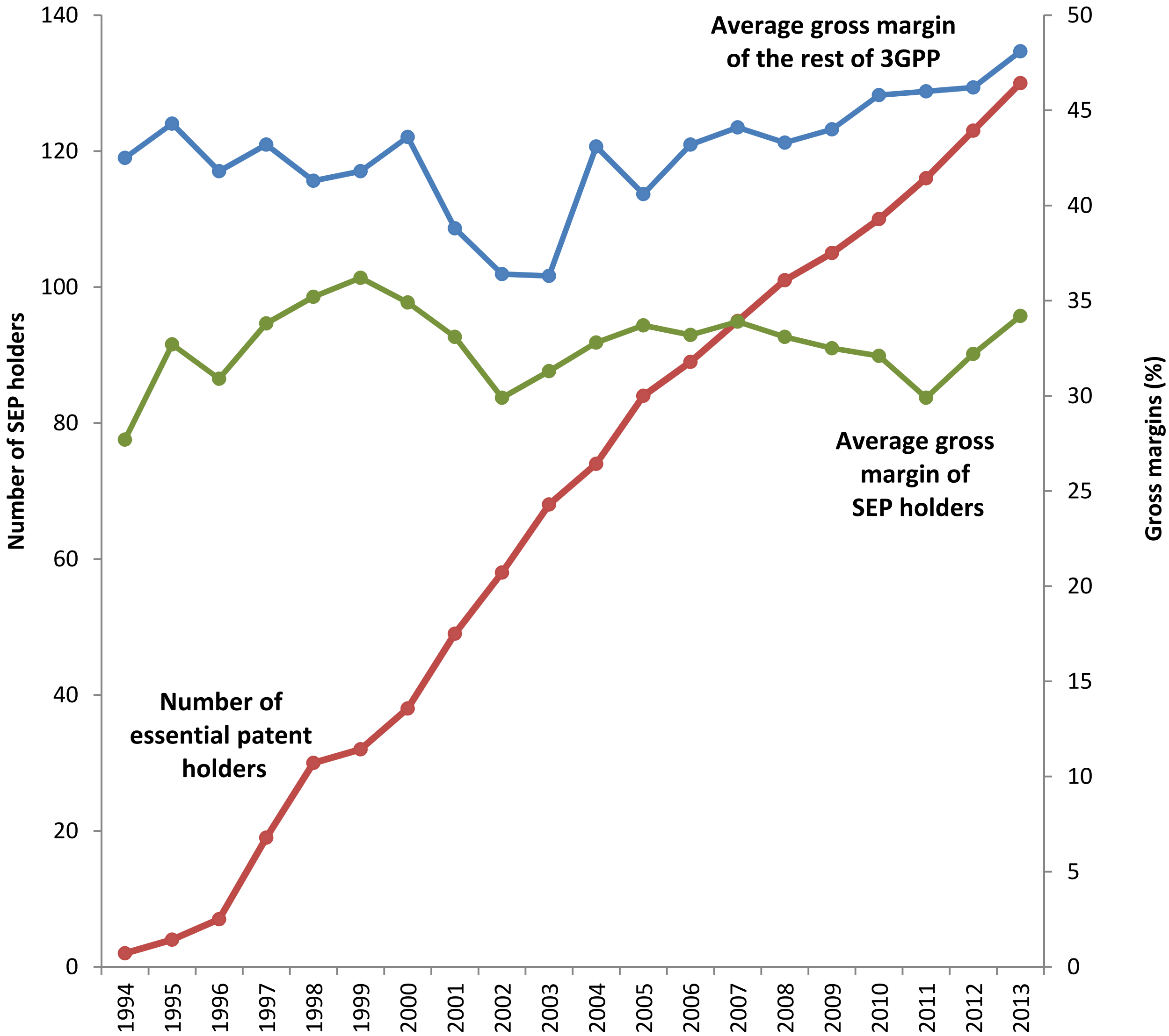


Figure 7
Average gross margins,
SEP holders (≥ 1 SEP) and rest of 3GPP
(device manufacturers)
(1994-2013)

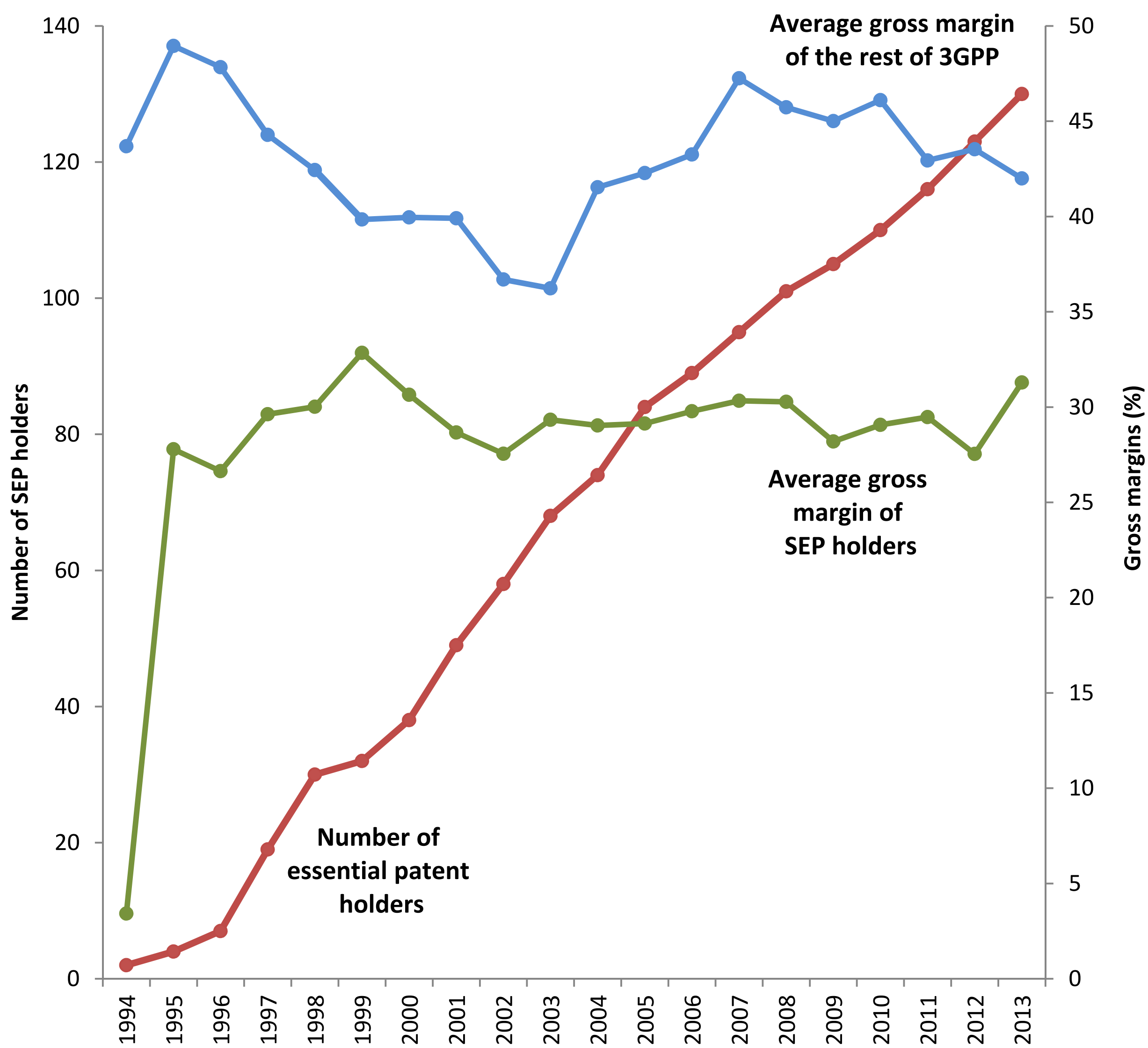


Table 1: The mobile wireless device manufacturing industry, 1994-2013

	(1) Number of essential patent holders (cummulative)	(2) Number of essential patents (cummulative)	(3) Average selling price, ASP ($2013)	(4) Number of devices sold (millions)	(5) Total sales (millions of $2013)	
1994	2	139	853	29	24.767	1994
1995	4	462	639	41	26.520	1995
1996	7	710	520	65	33.992	1996
1997	19	1.761	450	105	47.422	1997
1998	30	3.377	402	176	70.674	1998
1999	32	3.701	327	293	95.847	1999
2000	38	4.865	310	407	126.226	2000
2001	47	12.052	296	413	122.513	2001
2002	56	19.136	263	427	112.515	2002
2003	66	24.456	246	520	127.996	2003
2004	72	32.960	216	674	145.933	2004
2005	82	39.130	206	817	168.511	2005
2006	87	46.464	190	991	187.999	2006
2007	93	54.146	173	1.153	199.941	2007
2008	99	64.704	156	1.222	191.014	2008
2009	103	86.653	150	1.212	181.435	2009
2010	108	106.828	133	1.597	211.869	2010
2011	114	126.279	135	1.775	239.762	2011
2012	121	146.047	164	1.746	285.961	2012
2013	128	157.364	165	1.810	298.420	2013
Simple correlations						Simple correlations
Levels						Levels
SEP holders	1,00	0,90	–0,87	0,97	0,97	SEP holders
SEPs	0,90	1,00	–0,65	0,97	0,92	SEPs
Changes						Changes
SEP holders	1,00	0,00	–0,24	–0,06	–0,01	SEP holders
SEPs	0,00	1,00	–0,09	0,35	0,12	SEPs

Table 2: The composition of sales of wireless devices and real average selling price (ASP) per technological generation, 2007-2013

A. Share of devices (%)	2007	2008	2009	2010	2011	2012	2013	A. Share of devices (%)
2G(GSM)	10,1	7,1	7,4	4,8	3,0	1,5	-	2G (GSM)
2G	0,6	0,5	1,3	0,9	0,6	0,3	0,2	2G
2.5G(GPRS)	35,5	28,4	22,0	21,4	18,4	10,3	6,2	2.5G (GPRS)
2.5G	10,7	8,3	7,5	5,7	5,0	3,2	2,3	2.5G
2.75G(EDGE)	24,4	29,1	25,2	26,8	32,2	29,0	25,2	2.75G (EDGE)
3G	16,5	19,4	22,2	19,7	7,7	6,1	9,2	3G
3.5G	2,2	7,3	14,4	20,7	32,7	44,5	43,2	3.5G
4G	-	-	-	0,0	0,4	5,1	13,8	4G
Total (%)	100,0	100,0	100,0	100,0	100,0	100,0	100,0	(%) Total
Total units (mm)	1.153	1.222	1.212	1.597	1.775	1.746	1.810	Total units (mm)

B. Price (ASP) $ 2013	2007	2008	2009	2010	2011	2012	2013	B. Price (ASP) $2013
2G(GSM)	49	45	37	33	31	28	-	2G (GSM)
2G	84	60	54	50	45	41	39	2G
2.5G(GPRS)	108	70	57	38	32	29	28	2.5G (GPRS)
2.5G	157	113	106	76	33	27	25	2.5G
2.75G(EDGE)	198	156	131	102	85	51	43	2.75G (EDGE)
3G	334	247	197	145	121	93	68	3G
3.5G	428	413	338	302	271	258	206	3.5G
4G	-	-	-	344	375	475	409	4G

C. Price (ASP) 2007 =100	2007	2008	2009	2010	2011	2012	2013	C. Price (ASP) 2007 =100
2G(GSM)	100	91	75	67	62	58	-	2G (GSM)
2G	100	71	64	59	53	49	46	2G
2.5G(GPRS)	100	65	53	35	29	27	25	2.5G (GPRS)
2.5G	100	72	68	49	21	17	16	2.5G
2.75G(EDGE)	100	79	66	51	43	26	22	2.75G (EDGE)
3G	100	74	59	43	36	28	20	3G
3.5G	100	97	79	71	63	60	48	3.5G
4G	-	-	-	100	109	138	119	4G

Table 3: Gross margins and number of SEP holders

(Gross margins measured in percentage points)

	1	2	3	4	5	**6**
Number of SEP holders (ten)	−0.005	−0.135	−0.063	0.294**	0.345*	**0.253**
	(0.16)	(0.16)	(0.15)	(0.14)	(0.20)	**(0.21)**
SEP holder dummy (SEP holder = 1)	−7.36***	−5.66***	−5.85***	−5.50***	−5.78***	**−12.14*** **
	(1.29)	(1.44)	(1.46)	(1.35)	(1.35)	**(3.96)**
R&D intensity (one percentage of sales)		−0.003***	−0.003***	−0.004***	−0.004***	**−0.004*** **
		(0.001)	(0.001)	(0.001)	(0.001)	**(0.001)**
Total number of employees (thousands)		−0.078***	−0.094***	−0.076***	−0.076***	**−0.075*** **
		(0.01)	(0.01)	(0.01)	(0.01)	**(0.01)**
Capital stock (billions)		0.142***	0.212***	0.202***	0.204***	**0.195*** **
		(0.04)	(0.04)	(0.03)	(0.03)	**(0.03)**
Component manufacturer			−2.74**	−2.82**	−2.72	**−2.91**
			(1.20)	(1.18)	(2.76)	**(2.76)**
Device manufacturer			−13.24***	−9.01***	−7.20**	**−6.82*** *
			(1.40)	(1.42)	(3.36)	**(3.37)**
Other non-manufacturer			2.98	−5.78	3,76	**9.35**
			(4.01)	(3.97)	(17.57)	**(17.86)**
Country dummies				Included	Included	**Included**
mponent manufacturer x number of SEP holders					−0.016	**0.005**
					(0.30)	**(0.30)**
Device manufacturer x number of SEP holders					−0.210	**−0.259**
					(0.36)	**(0.36)**
ther non-manufacturer x number of SEP holders					−0.963	**−1.547**
					(1.71)	**(1.74)**
SEP holder x number of SEP holders						**0.680***
						(0.40)
R2	0.02	0.06	0.12	0.32	0.32	**0.32**
F	16.895	20.593	25.444	26.740	23.959	**23.288**
Observations	1,509					
Number of firms	148					
Period	1994-2013					

The base category for the industry group effects is "infrastructure manufacturer"
(Standard errors in parentheses)
*p<0.10, **p<0.05, ***p<0.01

Table 4: Gross margins and number of SEPs

(Gross margins measured in percentage points)

	1	2	3	4	5	**6**
Number of SEPs (thousand)	0.007	−0.001	0.004	0.022**	0.027*	**0.024**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	**(0.02)**
SEP holder dummy (SEP holder = 1)	−7.51***	−5.88***	−6.07***	−5.75***	−5.71***	**−6.75*** **
	(1.29)	(1.43)	(1.45)	(1.34)	(1.34)	**(2.12)**
R&D intensity (one percentage of sales)		−0.003***	−0.003***	−0.004***	−0.004***	**−0.004*** **
		(0.001)	(0.001)	(0.001)	(0.001)	**(0.001)**
Total number of employees (thousands)		−0.077***	−0.093***	−0.076***	−0.077***	**−0.076*** **
		(0.01)	(0.01)	(0.01)	(0.01)	**(0.01)**
Capital stock (billions)		0.141***	0.210***	0.201***	0.205***	**0.202*** **
		(0.04)	(0.04)	(0.03)	(0.03)	**(0.04)**
Component manufacturer			−2.83**	−2.87**	−2.85	**−2.90**
			(1.20)	(1.19)	(1.74)	**(1.74)**
Device manufacturer			−13.31***	−9.07***	−7.52***	**−7.42*** **
			(1.41)	(1.42)	(2.11)	**(2.11)**
			3.049	−5.764	−3.448	**−2.594**
Other non-manufacturer			(4.01)	(3.97)	(7.58)	**(7.70)**
Country dummies				Included	Included	**Included**
Component manufacturer x number of SEPs					−0.001	**−0.001**
					(0.02)	**(0.02)**
Device manufacturer x number of SEPs					−0.023	**−0.024**
					(0.02)	**(0.02)**
Other non-manufacturer x number of SEPs					−0.030	**−0.041**
					(0.08)	**(0.08)**
SEP holder x number of SEPs						**0.014**
						(0.02)
R2	0.02	0.06	0.12	0.32	0.32	**0.32**
F	17.163	20.566	25.627	26.921	24.146	**23.256**
Observations	1,509					
Number of firms	148					
Period	1994-2013					

The base category for the industry group effects is "infrastructure manufacturer"
Standard errors in parentheses
*p<0.10, **p<0.05, ***p<0.01