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SEP ROYALTIES: WHAT THEORY OF VALUE AND DISTRIBUTION SHOULD COURTS APPLY?

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SEP Royalties:
What Theory of Value and Distribution Should Courts Apply?

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Abstract

Courts are often required to determine the royalty to which the owner of a FRAND-encumbered standard essential patent (SEP) is entitled. We argue that courts should use the observed royalties charged by licensors, the market rental price of assets created by investments in R&D. This "comparables" technique is used to value virtually all classes of assets and is based on the standard theory of value and distribution, price theory. Price theory explains where value comes from, how it is distributed among inputs, and how monopoly power is exploited and measured.

We further argue that courts should discard the "bottom up" and the top down techniques. Both are based on the theory of patent holdup and royalty stacking. This theory assumes that any observed royalty is the result of "excessive royalties" wrought by the additional monopoly power conferred by standardization through patent holdup and royalty stacking. Nevertheless, the theory is incoherent and rejected by the available evidence.

Proponents of the "bottom up" technique claim that courts should value SEPs as the incremental value of the standardized technology compared with its next-best alternative, which was discarded when the SEP became part of the standard. This has never been operationalized, however, because competing technologies never made it to market. Also, the bottom up technique is based on faulty game theory that elides R&D, assumes that competing technologies are freely available, and has absurd antitrust implications for any proprietary standard and well beyond SEP intensive industries.

Proponents of the "top down" technique claim that courts should determine the value of SEPs by, first, determining the cumulative royalty that the entire suite of SEPs would have obtained competing with its next best alternative, and then apportioning it among SEP holders. The first step shares the conceptual and practical flaws of the bottom up technique. The second step assumes that each stage of production chain creates a fixed amount of value that is independent of the rest of the production chain and of consumer demand. This is contrary to the basic implications of standard economics.

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> Our conclusion is […] that the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation. Costs must be incurred if benefits are to be achieved.
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> Griliches and Jorgenson (1967)

1 Introduction

Courts are often required to answer an important question: what is the royalty to which the owner of a FRAND-encumbered Standard Essential Patent (SEP) is entitled? This question sometimes arises when an implementing firm sues a SEP holder, claiming that the SEP holder has violated its FRAND commitment by overcharging for its patents. At other times, the question arises when a SEP holder sues an implementer, claiming that the implementer has infringed its patents. Either way, the court has to decide the royalty to which the SEP holder is entitled.

We argue that when a functioning SEP licensing market exists, courts should use a technique of valuation often called "comparables," which is the standard approach they take for virtually all other classes of assets. That is, they should be guided by the observed royalty base and rate charged by licensors in the market, because a royalty is the rental price of an asset created by investments in R&D. This technique of valuation is based on price theory, the standard theory of value and distribution in mainstream economics. Price theory, moreover, allows researchers to distinguish between royalty rates that emerge from a competitive market and those that emerge from a monopolized market. It is therefore not just useful, but necessary, for courts to employ when assessing claims that a particular SEP holder is exercising monopoly power.

We further argue that courts should not rely on either the "bottom up" or "top down" techniques, which have been advocated by some competition authorities, academics, and industry consultants. Both the bottom up and top down techniques reject the idea that courts should use observed market prices as a guide to valuation, because any observed market price is the result of "excessive royalties" wrought by the additional monopoly power conferred by standardization.

Both bottom up and top down techniques of apportionment are based on the theory of "Patent Holdup and Royalty Stacking," which has been shown to fail tests for logical consistency, logical completeness, and fit between its predictions and the empirical evidence. A sizable literature shows that patent holdup cannot be a long-run equilibrium; that royalty stacking cannot be patent holdup repeated numerous times; and the strategic game that underpins patent holdup and royalty stacking is flawed in that it assumes that implementers invest in new products not knowing that they will have to pay patent royalties (Epstein, Kieff, and Spulber 2012; Sidak 2015; Galetovic and Haber 2017). There is also no positive evidence in support of the theory's core predictions (Denicolo et. al., 2008; Egan and Teece, 2015; Epstein, Kieff, and Spulber, 2012; Galetovic and Gupta, 2016; Galetovic and Haber, 2017; Gerardin and Rato, 2007; Geradin, Layne-Farrar and Padilla, 2008; Gupta, 2013; Layne-Farrar 2014; Sidak, 2015). Indeed, evidence from industries that should be canonical cases of patent holdup and royalty stacking display outcomes that are completely at variance with the predictions of the theory (Galetovic and Gupta, 2016; Galetovic and Haber 2017; Galetovic, Haber, and Levine 2015; Galetovic, Haber, and Zaretzki 2017). The importance of this fact cannot be understated: the core claim of the theory—that SEP holders are earning "excessive royalties"— is simply an assumption of the theory, not a fact that has been demonstrated. When researchers examine the evidence they find that the assumption is invalid (Galetovic, Haber, and Zaretzki 2017).

Flawed theories generate errors when applied in real world situations, and bottom up and top down techniques of apportionment are not an exception to that general rule. Once one assumes that SEP holders are earning "excessive royalties" a technique must be created by which courts can set the "right" royalty.

Bottom up holds that courts should value SEPs as the incremental value of the patented technology compared to its next-best alternative (which was discarded) at the time that the SEP became part of an industry standard. The technique cannot be operationalized: it requires that practitioners be able to identify, and know the market price of, an alternative technology that was nearly identical to the technology adopted but that never came into existence because it was discarded. As an empirical matter, it is not possible to know the price of something that did not exist.

Top down apportionment is an attempt to solve the practical problems inherent in bottom up apportionment, and in so doing generates yet another error. Recognizing that it is not possible to observe the market prices of alternative products that never existed, the practitioners of the top down technique hold that courts should determine the value of SEPs by, first, generating an estimate of the total value produced in a particular stage of a production chain, and then apportion the value of that stage among the firms operating in it, including the holders of SEPs. In doing so, practitioners of the top down technique violate a key concept in price theory: they posit that the value apportioned in one stage of a production chain is independent of and separable from the value produced across the entire production chain. The technique is not just wrong-headed, it is inherently arbitrary.

Ultimately, our main point is simple: in adjudicating the value of SEPs, courts should do what they normally do in pricing an asset or the flow of income it produces; rely on information from the market. This means that courts should ask experts about observed market outcomes—the royalty bases and rates actually paid by other licensees for a comparable patent portfolio licensed under similar temporal circumstances. Experts presumably have this knowledge, because they apply it in non-litigation contexts in order to advise clients in business decisions.

This paper proceeds as follows. In Section 2 we explain the fundamentals of price theory. We realize that price theory is a basic building block microeconomics. The fact that competition authorities and the practitioners upon whom courts rely often ignore it when it comes to making arguments about FRAND royalties requires, unfortunately, that we return to the basics. We then show how price theory can be a useful guide for courts to set royalties in a canonical SEP licensing industry; smartphones. We show that there is a functioning licensing market for smartphone SEPs, and that it is not characterized by the exercise of monopoly power. In section 3 we explore the "bottom up" approach to royalty setting, and explain why it is based on a flawed theory and why it cannot be operationalized as a practical matter. In section 4 we turn to the "top down" technique, and its SSPPU variant, and show why attempts to operationalize it require practitioners to depart from mainstream economics. Section 5 concludes.

2. The Comparables Technique

The comparables technique starts from the premise that when a functioning licensing market exists, observed royalties are the market rental price of assets—the SEPs—which can be used to value similar transactions. That is, if implementers A, B, and C pay on average a royalty of *x* percent for using the SEPs that read on a given technology, implementer D in the same market should either pay a similar royalty; or some royalty that departs from the average for observable market reasons.[2] We now explain the theory of value and distribution which underlies the comparables technique.

2.1 Price theory: a theory of value and distribution

In its different guises, the comparables technique is the method used to value virtually all classes of assets and determine their rental rates. This is unsurprising, because it is based on price theory, the standard theory of value and distribution in economics. Price theory was answers two key questions: 1) where does value come from; and 2) how is value distributed among inputs in a production chain? Price theory shows that the value created at the margin by an entire production chain is equal to the market price that consumers are willing to pay for the final good or service. This is true whether the good or service is a pound of steak, a gallon of gas, or a personal computer. Price theory also shows that the total revenues of producers of final goods are distributed among the providers of inputs according to the market prices that each receives. Thus, the sum of payments made to the producers of the inputs exhausts the revenues earned by the sales of the final product. Because there is one demand curve for a product, the total value that can be distributed among the providers of inputs to make that product is bounded by that demand curve.

A simple supply and demand graph based on the market for smartphones shows why all value stems from consumers' willingness to pay and how that value is distributed among input providers. Figure 1 shows a diagram of the observed equilibrium in the smartphone

[2] An example will clarify what we mean by "observable market reasons." Consider the market for natural gas. In an exporting country, the market price of natural gas at the head of the pipeline tends to be about $4 less per million BTUs than the fob price of natural gas on a ship that will export it overseas. This is because natural gas must be cooled and liquefied before it can be stored on a ship, and this process costs about $4 per million BTUs.

market in 2016. For simplicity, we have parametrized a linear demand curve with market data (see the Appendix).[3]

As can be seen in Figure 1, in 2016 phone manufacturers sold 1.42 billion smartphones for $425.1 billion, at an average selling price of $298.[4] Because consumers are free to buy a phone or not, the demand curve shows how much consumers value a smartphone at the margin. That is, as a matter of theory, $298 represents how much the least willing consumer in 2016 was willing to pay for the average smartphone. Figure 1 also shows that most consumers valued their phones at more than $298. Consequently, most consumers obtained a net surplus when they bought a phone, the difference between their willingness to pay, as shown by the demand curve, and the market price of their smartphone of choice. It follows that the total consumer surplus was equal to the area between the demand curve and the market price for phones. According to the demand curve depicted in Figure 1, consumer surplus in 2016 was equal to $784 billion.[5]

As Figure 1 also shows, the revenues generated by the sale of smartphones were distributed among phone manufacturers and input suppliers. Roughly 20 percent of the revenue from smartphone sales reached semiconductor manufacturers ($85 billion; $60 per smartphone, on average), five percent reached the manufacturers of baseband processors ($22 billion; $15 per smartphone, on average); and 60 percent of the revenues ($254.1 billion; $178 per smartphone, on average) reached the producers of other inputs, such as the firms that made the cameras, gorilla glass, and housings, as well as the firms (such as Foxconn) that

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[3] To draw the intercept of the linear demand curve on the price axis we used the fact that 2G phones, which were considerably inferior devices compared with a 2016 smartphone, were introduced at $1,400 in 1992. Indeed, when 2G phones were introduced they lacked data service beyond SMS and could not send emails. Data services were not introduced until years later. See Galetovic, Haber and Zaretzki (2017).

[4] The August 2017 update of the database which shows the sources and calculations in detail is available in an Excel workbook that we have posted to the web at https://hooverip2.org/working-paper/wp18005. Galetovic, Haber, and Zaretzki (2018) provide a discussion of the database and its construction.

[5] This is equivalent to about 1 percent of world GDP.

actually assembled the phones. Roughly 12 percent ($50 billion; $35 per smartphone) reached the firms that designed and marketed the phones as profits, most of which accrued to Apple.

Figure 1 also shows how much of the revenue generated by the smartphone market reached the owners of patents and other intellectual property. Just over three percent of the revenues (3.3 percent or $14.2 billion to be exact, or roughly $10 per smartphone) reached patent holders, many of them owners of SEPs ($12.4 billion; roughly $10 per smartphone, on average). In addition, a tiny sliver of the revenues equal to about 0.1 percent of the revenues (roughly $400 billion; about 30 cents per smartphone) reached ARM, the firm that designed the architecture of the processor that runs roughly 95 percent of smartphones, as payment for its intellectual property

On what basis were the $425.1 billion in revenues from the sale of smartphones in 2016 distributed among the inputs along the production chain? The key is that all firms substituted away from expensive inputs towards cheaper inputs. Thus firms at the end of the production chain, which designed and marketed the phones (e.g., Samsung, Apple) combined inputs (e.g., labor, capital, intermediates, intellectual property) to produce the smartphones that consumers valued at minimum cost. Similarly, the firms that produced the intermediate inputs and intellectual property for those smartphones (e.g., Corning, Ericsson) also combined inputs to minimize costs, and they, in turn, hired workers and purchased the necessary inputs from firms further down the production chain, and so on. At the same time, and because every firm along the production chain only produced what ultimately contributed to the value of the final product as determined by consumers, each input had its own demand curve, ultimately derived from the demand for smartphones, whose elasticity depended on substitution possibilities.[6] Consequently, firms along the production chain equalized the value created by each input at the margin with the input's market price. The share of each input in the $425.1 billion in revenues in the smartphone market, therefore, was the equilibrium outcome of a complex process of cost minimization and profit maximization. Because the output of a firm in an upstream stage of the production chain is the input of firms further downstream, and all value stems ultimately from consumers' willingness to pay, no stage of the production chain was independent of and separable from the others.

The same principles can be applied to the royalties earned by the owners of the intellectual property assets necessary to make a smartphone work. Royalties are the rental rate for the use of the intellectual property assets (the patents). That rental rate is a function of the value that consumers are willing to pay for the capabilities created by those patented technologies, at the margin, and the possibilities that producers had to substitute away from using those intellectual property assets toward alternatives. To be concrete, the finding that the patent holders earned 3.3 percent of the value of the average smartphone in 2016 has two (perhaps complementary) interpretations: 1) the purchaser with the lowest willingness to pay for the average smartphone valued those technologies in the equivalent of 3.3 percent of the price she paid for her smartphone; 2) there were alternative inputs available to producers. And given that a patented technology is not a physical input, an obvious alternative for producers was to infringe the patents. The 3.3 percent therefore represents a lower bound estimate of the value of the patented technologies to the marginal consumer.

We hope that by now it is evident that the point of price theory is not to determine the "right" price for any final good or any input. Rather, price theory is an explanation of the

[6] The rules governing derived demand have been known since Alfred Marshall's *Principles*. For a formal treatment see Brofenbrenner (1961). See also Stigler (1987) and Whitaker (1991).

process whereby equilibrium relative prices for products and inputs emerge out of the complex adaptive system that economists call a market economy. It explains the systematic link between consumer tastes and costs of production. Consequently, price theory is a rich generator of testable implications that can be falsified with data—such as, is the market for a particular input a monopoly—but it is not a blueprint to build a machine to calculate prices and dictate the resource allocation that should emerge in a particular situation.

Price theory is not a blueprint to build a price-computing machine because no individual agent in the market—neither a consumer nor any particular producer at any particular point in the production chain—knows the entire production chain, the structure of demand, or the myriad non-linear feedback loops within the production chain (e.g., how price signals from a firm further up the production chain affects the decisions of a firm further down the production chain) that would be necessary to calculate the "right" market prices. [7] The whole point of letting markets set prices is that they economize on information: no agent has to (and indeed, can) fully understand the exact process whereby the market aggregates the information that results in the equilibrium price for the final good and the equilibrium price for all inputs. Precisely because a market economizes on information, no calculation exercise can expect to replicate it.

This does not mean that individual agents in the market act blindly. It means that they make decisions by looking at signals that provide feedbacks to them. These price signals aggregate information about value and costs at other points in the production chain and the reactions of their competitors. They are generated by a large number of market exchanges

[7] Arrow (1988), pp. 277-78, provides a simple example to illustrate both positive and negative feedbacks in a decentralized market. "…consider a world with just two commodities, bread and butter. At the initial prices, suppose that the demand for bread exceeds the supply, while the supply of butter exceeds the demand for it. The price of bread rises, while the price of butter falls. But the demand for bread certainly increases when the price of butter falls, and it can happen that the net effect is to increase the demand for bread, thereby amplifying the initial deviation."

that they do not observe directly. It is precisely because the prices aggregate information that a consumer does not need to know the price of DRAM chips in order to determine whether she is paying the market price for a laptop computer, and the producer of the DRAM chips does not need to know the price of the chemicals necessary to make the liquid crystals in the laptop's LCD display. The prices generated in a market are precisely why markets are much more efficient than other ways of organizing production: they economize on information. No agent needs to have knowledge—or even can hope to have knowledge—of every stage of production, the feedback loops among them, and how those feedbacks operate as a system to meet consumer demand and distribute the value it creates.

2.2 Economic rent and the distribution of value across the stages of the production chain

In general, the market price of an input compensates for the opportunity cost of providing it, but if total revenue at market prices exceeds the input's opportunity cost, the owner receives an economic rent.[8] One source of economic rent is monopoly and, more generally, market power—the owner of the input increases its market price by restricting output. This is the primary concern of antitrust authorities. Another source of economic rent is scarcity: the market price of an input exceeds its opportunity cost because the total quantity of the input is fixed; Finally, there are Ricardian rents, which remunerate differential productivity: the ability to produce more revenue per dollar of input than the marginal producer. Scarcity rents and Ricardian rents have nothing to do with market power. Thus in our example, the rent earned by smartphone manufacturers (roughly 12 percent of all phone revenues) mostly stems from the fact that one of them—Apple—is able to sell iPhones at about three times the price charged by other manufacturers, while its production costs are only

[8] On the types of economic rent see Noll (2005).

twice as high. Thus, because consumers value iPhones more than other phones, Apple obtains more revenue per dollar of input than its competitors, and earns a Ricardian rent.[9]

Regardless of the origins of the rents, the total revenues of an industry are equal to the sum of the payments to the inputs plus economic rent. This point is also a fundamental insight from price theory: in equilibrium, the rents earned by any firm, whatever their origin and wherever their location in the production chain, are bounded by the demand curve for the final product, and the payments to other inputs.

We cannot stress this last point strongly enough: no input is of any value unless it is used to produce what consumers value. Thus, any attempt by an expert to apportion value to any input, including a patented technology, must take into account consumer demand for the *final* product, the payments to *all* inputs across the entire production chain (not simply at one stage of the production chain), and the rents earned by all the firms in the supply chain, including the implementer that sells the final product into the consumer market. No stage of the production chain is independent of the others. It follows that each stage of the production chain cannot be characterized by a fixed pie of economic rent. Any valuation method based on that premise would have no basis in economic theory.

To see the implications of this fact at work we return to our example of the smartphone industry. The source and limit of all surplus in the smartphone production chain is the value that consumers assign to the things that they can do with a smartphone: neither the technologies that make smartphones work, nor the components used to manufacture them, are valuable by themselves. On the contrary, they have value only because they contribute to producing smartphones that do things that consumers value. It follows that the royalties

[9] Consumers who buy iPhones must be better off despite paying Apple's substantially higher prices, because they could have bought cheaper phones of another make, but they didn't.

earned by the owners of the SEPs necessary to make smartphones work, *regardless of where they are earned in the production chain*, are capped by net surplus, the difference between the willingness to pay of consumers for a smartphone, and all the other costs of producing a smartphone across the entire production chain. As can be seen in Figure 1, in 2016 the equilibrium outcome of this process was that patent owners, including those who owned SEPs and those who owned non-SEPs, received 3.3 percent of all revenues in the smartphone market.

2.3 Price theory and monopoly power

A fundamental insight of price theory is that there is only one way to exploit monopoly power; restrain output and raise the market price. The key difference between a monopolist and a firm operating in a competitive market is that the monopolist can raise the price by reducing output but the firm in a competitive market cannot. Both produce to the point that marginal revenue equals marginal cost, but from the point of view of the monopolist the demand curve is downward sloping (as it restrains output, prices rise), while from the point of a firm in a competitive market the demand curve is flat (as it restrains output, prices stay the same).

Price theory provides a technique to determine whether a firm in the market is exercising monopoly power; the famous Lerner formula.[10] Thus, if c is the long-run marginal cost of manufacturing, P is the price of the good and η is the elasticity of demand (the slope of the demand curve), a monopolist will price so that

[10] See Lerner (1934) and Noll (2005).

$$\frac{P-c}{P}=\frac{1}{\eta}.$$

The Lerner formula tightly condenses information about the entire production chain (in *c*), the demand for the final good (in the price elasticity η), and the market equilibrium (the equality). For this reason, it is deceptively simple and many of its implications, both theoretical and practical, are often overlooked.

Begin with *c*. As we have seen, the long run marginal cost of producing a good is equal to the sum of payments made to inputs across the entire production chain. It follows that it is *not* necessary to produce the final good to exploit monopoly power. On the contrary, any provider of an essential input for which there is no substitute in any part of the production chain can exploit monopoly power. The insight can be traced back at least to Spengler (1950).[11] When manufacturers use an input in fixed proportions to produce a final good, monopoly power can be exploited from any stage of the production chain.

Next consider the demand for the final good, which appears in the Lerner formula through the price elasticity of the demand, η. It is straightforward to see that the less elastic the demand for the final good, the larger the equilibrium Lerner margin. It is also sometimes overlooked, however, that if any agent in the production chain exercises monopoly power, the Lerner margin will be rather large, even for fairly large elasticities of demand. For example, if the elasticity of the demand for the final good is 2 in equilibrium (a one percent increase in price causes the quantity demanded by consumers to fall by two percent), the Lerner margin

[11] See also Tirole (1988, p. 174).

equals 50 percent. That is, at the margin, half of the price that consumers pay for the final good is monopoly rent.[12] Firms that enjoy monopoly power are very profitable indeed.

We can understand how monopoly power works with the help of our example, the market for smartphones. Figure 2 shows the same demand curve as Figure 1, but the market equilibrium is modified by assuming that patent holders enjoy monopoly power and act as a single profit-maximizing entity. What would have been the smartphone market equilibrium in 2016?

Let us perform some rough calculations based on a comparison of Figures 1 and 2. Instead of earning 3.3 percent of all smartphone revenues, the patent holders acting as a single monopolist would have earned 66 percent of the revenues. Those higher royalties would have driven up the average selling price of a smartphone from \$298 to \$844 dollars. As a consequence, the firms that design and market smartphones would have sold only 722 million units, instead of 1.42 billion. Even with the decline in unit sales, however, the higher prices would have pushed the total revenues of the up, from \$425.1 billion to \$609.4 billion. Because the origin of the higher market price would have been the exploitation of monopoly power by the patent holders, more than two-thirds of those revenues (about \$400 billion) would have been pure economic rent accruing to the patent holders—revenues that exceeded the opportunity cost of the inputs used to produce the patented technologies. Economic profits of patent licensors would have been astronomical, of the order of 0.6 percent of world GDP!

Now things get really interesting, because the distribution of revenues and rents across the entire production chain has to radically adjust to account for the fact that the patent

[12] Empirical studies indicate that measure the elasticities of demand for final goods yield price elasticities that are typically around one. For example, Blundell (1988) reports the following elasticities for group of consumer products : food: 0,494; fuel: 0,747; clothing: 0,852; transport: 0,674; services: 0,767. Only the elasticity of the demand for spirits is close to two: 1,983.

holders are able to act as monopolists, taking 66 percent of all revenues. Market prices still determine the revenues and rents, but everyone up and down the production chain is forced to adjust prices and output. Our rough estimates indicate that the revenues of semiconductor manufacturers would have fallen from $85 billion to $43 billion, and their share of total smartphone revenues would have decreased from roughly 20 percent to about seven percent. Similarly, the revenues of baseband manufacturers would have fallen from $22 billion to $11 billion, and their share of total smartphone revenues would have decreased from roughly 5 percent to less than two percent. The revenues of the manufacturers of other inputs and the firms that assemble smartphones would have fallen from $254 billion to $123 billion, and their share of total smartphone revenues would have decreased from roughly 60 percent to about 21 percent. The healthy profit margins of the firms that design and market smartphones would have collapsed from roughly $50 billion to about $25 billion, and their share of total smartphone revenues would have fallen from 12 percent to about four percent.

The endogenous adjustment of the distribution of revenues across the entire production chain that would have been the consequence of monopoly power being exploited by patent holders has three important implications for courts. The first is that the only source of monopoly rent is the ability to raise price and constrain output of the final good. This is apparent from the Lerner Formula, where the entire demand is summarized by a single parameter, the price elasticity of the demand for the final good. It follows that if any agent in the production chain enjoys monopoly power, it will exploit it to the full extent, regardless of the source of that monopoly power by ultimately increasing the price paid by consumers. Therefore, claims made by some academics and competition authorities that SEPs grant different types of monopoly power—one on the basis of the patented technology, and a second based on the appropriation of the value of standardization, and that these are independent and separable—have no basis in economic theory.

The second implication is that when an input provider exercises monopoly power in one stage of the production chain, it will still be obtaining its rent from what consumers of the final good pay. The monopolist is exploiting consumers, not the other firms in the production chain. It follows that whether the monopolist exploits its power by charging a percentage of the final price of a good or a percentage of the price of an input to produce that good is irrelevant.

Third, and perhaps of greatest relevance to a court, price theory is necessary and sufficient to assess whether an input provider located in any stage of the production chain is exercising monopoly power. Price theory is necessary because it is a coherent and logically consistent theory that generates testable implications. Price theory is sufficient because it provides a way to measure the exercise monopoly power: the monopoly rents are going to show up in the revenues, profit margins and income statements of the monopolist. To see how this works, let us return to the example of the smartphone market. Had there been a monopoly at work—had any single one of the many firms that license SEPs been operating as a monopoly, or had the SEP holders joined together to operate as a single monopolist, the observed royalties would have been 15 to 20 times higher than those that we actually observed—on the order of 66 percent of revenues instead of 3.3 percent of revenues. Thus, market data shows that for whatever reasons, firms who design and market smartphones perceive opportunities for substitution such that SEP holders are unable to operate as monopolists.

2.4 Royalties and licensing markets

In a market economy, firms operate with the expectation that they will make a profit. They therefore make investments in R&D in the expectation that they will be able to appropriate part of the value of the technologies they create. One very common approach to appropriating that value is the creation of an intellectual property right in the technology. Indeed, without the property right that allows the firm to appropriate the value of a new technology, the incentive to develop that technology in the first place, or to invest in the commercialization of that technology, largely evaporates.[13] As Griliches and Jorgenson (1967, p. 274) pointed out long ago, "[…] the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation." A patented technology is therefore just like any other type of capital asset: its value accrues over time, and depreciates over time. At some point, like other capital assets, it ceases to have any value—in the case because the technology is rendered obsolete by further technological advance.

The outcomes of investments in R&D are better technologies that make inputs more productive or create new (or better) products that are valued by consumers. When new inputs or products are better than their older substitutes, and rights over intellectual property are clearly defined and enforced, those inputs or products receive a premium in the market—a price differential over the alternatives. It is precisely this premium, and the possibility that firms and consumers can substitute towards better inputs and products, that give firms incentives to invest in R&D and innovate in the production chain.

As with any other capital asset, the owners of intellectual property will either use it directly or rent it in the market in order to appropriate the value it creates. In some cases, the

[13] There are other mechanisms by which a firm may appropriate the value of its R&D, such as political lobbying for restrictions on entry that might allow it to earn a market power rent.

owner of the new patented technology will directly exploit it, by producing a better input or a better final product. In those cases, no direct rental price for intellectual property will be directly observable; the rental price of the intellectual asset will be implicit, baked into the price of the physical product manufactured by the firm. In other cases, the owner of a patented technology will license it to others in exchange for a royalty, letting them produce the better input or final product. The market price for intellectual property in this case will be observable; it is the licensing royalty.[14]

It follows that in industries where specialized firms produce and license patented technologies to other firms in the production chain, royalties are the rental market price of an intellectual property asset.[15] As with any input, the equilibrium rental price of a given intellectual property asset is determined by the interaction of the derived demand for it and its supply. That derived demand is a product of two forces: the demand for the goods produced with the input, which consumers value; and the possibilities for other firms the production chain to substitute away from it, which might include different physical inputs or different intellectual property. In short, in a functioning market, the rental market price of intellectual property—the royalty—is the value assigned to it by the market at the margin.

Whether that rental market price reflects any monopoly power will crucially depend on substitution possibilities at the margin, not on the mere existence of an intellectual property right. At one extreme, the technology may be unique, as is the when a patented

[14] According to Johnson (2015, p. 198): "A royalty is simply a payment of a fixed fee per item sold ($5 per television set), or a percentage of the licensee's list price for each item, or a percentage of the licensee's receipts from sales […]". According to the *Oxford English Dictionary* "[A royalty is a] sum paid to a patentee for the use of a patent or to an author or composer for each copy of a book." See also OECD (2008). A "running royalty" is a payment that varies with the number of units sold. A "lump sum royalty" is a fixed payment that does not vary with the number of units sold.

[15] Estimating the value of the services rendered by a technology at the margin is not straightforward when the user is also the supplier and owner of the intellectual property. As Griliches and Jorgenson (1967) point out, however, the same difficulty occurs when the user of a piece of physical capital is the same firm that invested in that piece of physical capital. When a particular piece of capital can be rented in a market, the market rental price is the accurate value of the services rendered by that piece of capital at the margin.

pharmaceutical is the only cure for a particular disease. In that case, the owner of the intellectual property is in the position to earn a monopoly rent, at least until a substitute, non-infringing pharmaceutical is developed or the patent expires. Importantly, the source of the monopoly power rent is not the property right; it is the absence of substitutes.[16] At the other extreme, the technology may compete with many alternatives. In that case, the premium that the owner of the intellectual property will earn is determined by the value of the differential improvement over those alternative technologies. In both cases, however, value and its distribution will be determined by the same forces that determine value and its distribution in any market. As price theory suggests, it depends fully on substitution possibilities at the margin across alternative technologies. And as price theory shows, whether a firm is able to exert monopoly power or faces substitutes for its technology can be empirically assessed by measuring the level of royalties—no other test is needed.

It follows from the preceding discussion that when courts apply the comparables technique, they are not trying to replicate the process whereby the market arrived at the observed royalty. The court is not trying to understand how and why consumers put a particular value on the final good. It is not estimating the value of A's patents by trying to understand any particular stage in the production chain. Rather, the court is observing the market equilibrium—an outcome of a set of complex and non-linear positive and negative feedback loops involving consumers and all the producers in the supply chain—by taking advantage of the fact that market prices aggregate and economize on information.

[16] When several patented pharmaceuticals compete in providing treatment to any given disease, the owners of those patents are not in a position to earn a monopoly rent.

2.5 How can courts tell when a licensing market works?

How can courts determine whether there is in fact a functioning licensing market? Let us again return to the example of the smartphone industry. One hallmark of a functioning market is that there is a set of market-specific practices according to which firms behave. Those behaviors are the outcome of the emergent process that determines the equilibrium of the market. In the smartphone market, the nature and outcome of each licensing negotiation depends on the specific characteristics of each deal, but several licensing practices are well established in the industry.[17] To begin with, licensors and licensees typically negotiate royalties for portfolios of patents. They do not write separate contracts for each patent. In addition, since the inception of the mobile phone industry, the outcome of a licensing agreement is a combination of a lump-sum royalty and a running royalty assessed on the average selling price of each phone. Blecker, Sanchez, and Stasik (2016) report, in fact, that holders of large patent portfolios have routinely licensed their entire portfolio for a single running royalty. Implementers and patent licensors also routinely grant each other cross licenses. As a matter of determining royalties, however, cross licenses are less important than in other industries, because most licensors in the mobile phone production chain are not downstream implementers.

A second indicator of a functioning licensing market in the smartphone industry is the fact that there is a remarkable degree of vertical separation across the smartphone production chain, in which there are numerous firms that specialize in developing and licensing the necessary technologies. The major patent licensors do not, in fact, manufacture smartphones. Ericsson and Nokia used to be handset manufacturers; as is well known, they are no longer in

[17] On the history and evolution of licensing practices in the mobile phone industry see, for example, Blecker, Sanchez and Stasik (2016). For general treatment of licensing practices see Johnson (2015) and Battersby and Grime (2017).

that business. Qualcomm deployed a full-fledged network in San Diego and manufactured handsets, but it did so in order to show that CDMA worked. Once it demonstrated the value of CDMA it exited phones and equipment manufacturing, and concentrated on technology development and chip design and manufacturing, but did so without owning a chip manufacturing plant.[18] Interdigital never manufactured a phone, and no longer produces any physical inputs; it develops technologies that make smartphones work, and earns all of its revenues from licensing. On top of these major licensors, there are scores of smaller firms that specialize in technology development and licensing, some of which are so small that they license their technologies through patent pools, rather than bear the cost of maintaining a licensing division (Galetovic, Haber, and Zaretzki, 2018).

The high degree of vertical separation in the industry can be seen by the fact that the firms that design and market smartphones are not important contributors to the underlying technologies. The PricewaterhouseCoopers 2017 Global Innovation 1000 study provides data on R&D spending and revenues enumerated at the firm level for large firms covering the period 2011-17. The study reveals that over the period 2011-17 Apple spent barely three percent of its revenues on R&D, while its major competitor, Samsung Electronics spent eight percent. The firms that licensed technologies to them outspent them by wide margins: Ericsson spent 15 percent of its revenues on R&D, Nokia spent 21 percent, Qualcomm spent 21 percent, and Rambus spent 39 percent.[19] In point of fact, vertical separation and specialization even exists in the semiconductor industry that provides one of the key inputs to smartphones. The firm that designs the processor cores that power 95 percent or more of all

[18] See Nenni and McLellan (2013).

[19] The PwC study and dataset are available at https://www.strategyand.pwc.com/innovation1000. InterDigital, which is too small to be listed in the PwC 1000, spent 15 percent over the period 2011-16 (Maurer and Haber 2018).

smartphones—ARM—is a technology company that simply licenses the design of its processor cores through the foundries that manufacture semiconductors.[20] Such a high degree of specialization would not occur without a functioning market.

A third indicator of a functioning licensing market is the steady royalty rates earned by the firms that specialize in technology development. Galetovic, Haber and Zaretzki (2018) estimated a time series of the average cumulative royalty yield in the smartphone industry covering 16 licensors that reported their royalty revenues since 2007 (which accounted for 78.2 percent of all royalty revenues in 2016); and for 22 licensors that reported their royalty revenues since 2009 (which accounted for 92.5 percent of all royalty revenues in 2016). As Figure 3 shows, both series are remarkably stable. The average cumulative royalty yield of firms with data since 2007 hovers between 2.1 and 3 percent; the average cumulative royalty yield of firms with data since 2009 hovers between 3 and 3.5 percent, falling only marginally during the last three years.

The stability of the average cumulative royalty yield over time is remarkable, considering the large changes in the mobile phone market since 2007. For example, as can be seen in Figure 4, the composition of sales between feature and smartphones changed significantly over the period and the value of sales roughly doubled—yet the average cumulative royalty yield remained stable. This suggests an equilibrium market price and outcome. The evidence also suggests stability in royalty yields across the major firms. The identities of the main licensors varied little from year to year. In sum, smartphones do not appear to be an industry in which new licensors emerge out of nowhere and disrupt the market by charging royalties out of sync with other licensors based on new business practices.

[20] See Nenni and Dingee (2015).

3 The bottom-up technique

While price theory provides a complete and logically consistent framework to assess monopoly power exercise in any industry, experts, as well as competition authorities such as the FTC and the European Commission, often advocate for a different technique for courts in setting FRAND royalties, "bottom up."

Underneath the bottom up technique is the theory of patent holdup and royalty stacking, which posits that licensing markets are characterized by monopolists earning excessive royalties. The argument runs as follows. When a group of downstream manufacturers chooses a particular patented technology as the standard for an industry, they knock firms that developed alternative technologies out of the market. The firms whose patented technologies are chosen to be part of the standard are now free to charge whatever price they like, and so, they price as monopolists. The manufacturers cannot refuse these outrageous demands because they are locked in, on the one hand, by their own investments, which were made on the basis of the selected standard, and on the other, by consumers who would now balk at switching to products that use an alternative technology because their devices would no longer be compatible with those owned by other consumers.[21] That is, the firms whose patented technologies have been chosen are now able, at least according to the theory, to "hold up" manufacturers and appropriate the value of standardization itself because the royalty rates have been set "ex post," rather than "ex ante."[22]

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[21] See, for example, Michel (2011) and Contreras and Gilbert (2015).

[22] An astute reader may notice that patent holdup theory conflates two different economic mechanisms: holdup and the exercise of market power. Holdup means that one firm appropriates another firm's quasi rent—its revenues minus its short-run costs—through opportunistic behavior. A firm that is being held up, by definition, does not generate enough revenue to cover its long-run costs. Therefore, the firm will not reinvest once its capital wears out. This is not a long-run equilibrium. Market power, by contrast, means that a firm can set prices such that it appropriates a monopoly rent from a market. The exercise of market power

There are many variants of this conjecture in the literature (Galetovic and Haber 2017). Cary et al. (2011) provide a concise formulation.

> Selecting a standard ordinarily requires an SSO to choose among competing technologies, and the process frequently results in a collective selection of a patented technology to the exclusion of other patented or non-proprietary technologies. Consequently, standardization necessarily entails the exclusion of alternative technologies […]. Indeed, because the opportunistic conduct resulting in patent holdup specifically "concerns the inefficient acquisition of market power," many commentators have "generally assumed that [such] opportunism in the standard-setting process is an antitrust problem."

The conjecture is not simply a matter of academic theorizing, but has been embraced by competition authorities. Hesse (2013), speaking as a DOJ official, articulated it as follows:

> Once a standard becomes established, firms implementing the standard may find switching away more difficult and expensive. This lock-in confers market power on the owners of the incorporated patents […]. Standards essential patent holders may seek to take advantage of the market power that standardization of their patented technology creates by engaging in hold-up. […]This type of hold-up raises particular competition concerns when alternative technologies that could have been included in the standard were instead excluded from it.

The theory of patent holdup and royalty stacking claims, in addition, that such opportunistic behavior can be practiced simultaneously by many firms, giving rise to a

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can be a long-run equilibrium, because the downstream firms will cover their long-run costs and continue to reinvest as their capital equipment wears out. Thus, holdup and the exercise of market power are two different, mutually inconsistent economic mechanisms. One cannot simultaneously have a long-run equilibrium and not have a long-run equilibrium. The conflation of holdup and market power leads to an additional conceptual error. The theory claims that the same manufacturing firms can be held up many times over, resulting in royalty stacking. Holdup cannot, however, occur many times over to the same firm. A firm's quasi rents (the difference between its revenues and its short-run costs) can be extracted only once. Any attempt to extract more revenues would cause the firm to shut down. Royalty stacking, by contrast, is about the exercise of market power by multiple input suppliers to downstream firms. Although this multiplicity of input suppliers might be an inefficient organization of a market, it nonetheless can be a long-run equilibrium, unlike holdup. The origins of these conceptual errors appear to be rooted in the mistaken claim that "patent holdup" is a variant of holdup as it is understood in the field of transaction cost economics, instead of being sui generis. See Galetovic and Haber (2017) for a more complete discussion.

phenomenon termed royalty stacking. As Lemley and Shapiro (2007) state in their seminal paper: “As a matter of simple arithmetic, royalty stacking magnifies the problems associated with injunction threats and holdup, and greatly so if many patents read on the same product.”

The purpose of “bottom up” apportionment is, therefore, to remove the undue monopoly power of the SEP holders, and the technique to accomplish this, according to its proponents, is to carry out an exercise that restores the competitive situation that prevailed before an SDO selected a technology that became the industry standard. That is, a court should “[identify] the set of alternatives that would have been available prior to standardization and then [determine] the incremental value, if any, of the SEPs relative to those alternatives.”[23] The FTC is quite explicit that this is the appropriate basis by which courts should set royalties:

> Courts should recognize that when it can be determined, the incremental value of the patented invention over the next-best alternative establishes the maximum amount that a willing licensee would pay in a hypothetical negotiation. Courts should not award reasonable royalty damages higher than this amount.

The bottom up technique is, however, fraught on a number of grounds, some empirical, and some theoretical. Let us pursue them systematically.

3.1 Assumptions instead of empirics

One might think that the first stage of the bottom up technique is to demonstrate that monopoly power is, in fact, being exercised by SEP holders. After all, it is the contention that royalties are excessive that justifies the entire exercise.

As we discussed in Section Two, the exercise of monopoly power is a testable hypothesis. There is only one demand curve for a product; any rent that can be extracted by a

[23] See Leonard and Lopez (2014). On this, see also FTC (2011, p. 189).

monopolist anywhere in the production chain is bounded by that demand curve. Thus, the monopoly power hypothesis can be tested by estimating a demand curve, estimating the royalty rate that would be charged by a profit-maximizing monopolist facing that demand curve, and then comparing that predicted royalty rate to the rate actually observed in the market. Such exercises are not, of course, exact—but when predicted values are larger than observed values by large magnitudes (or by more than an order of magnitude, as we show in Figures 1 and 2, regarding the smartphone market), then the rules of scientific inquiry would require the rejection of the monopoly power hypothesis.

This is not, however, how the technique of bottom up apportionment proceeds. Practitioners simply assume that royalties are excessive, because the theory of Patent Holdup and Royalty Stacking claims that it must be so. By assumption, any royalty that is being observed is a product of monopoly power.

One might object to such an empirical test by claiming that the situation in SEP-intensive industries is complicated by royalty stacking (the existence of multiple SEP holders, each exercising monopoly power independently). No single SEP holder will be able to charge as if a monopolist, because her royalties are bounded by those imposed by other monopolists.

Such a claim would not, however, stand up to scrutiny, because the same techniques that allow a researcher to identify whether a SEP holder is operating as a monopolist also allow her to test the hypothesis of royalty stacking. Formally, it can be shown that when there are n input providers and each posts her price independently, the equilibrium Lerner margin is

$$\frac{P-c}{P}=\frac{n}{\eta}.$$

That is, the single monopoly margin is multiplied n times. Each additional monopoly royalty rate added to the stack necessarily reduces the royalty rate that can be charged by other monopolists, with the consequence that the royalty rate charged by each monopolist is lower than that which would be charged by a single monopolist, but the aggregate royalty rate (the sum of the individual rates) is higher than that which would be charged by a single monopolist. This aggregated royalty rate can be estimated, and then compared to the aggregate royalties observed in the market.

Let us return to our example of the smartphone industry to show how such a test for the existence of a royalty stack works. In Galetovic, Haber and Zaretzki (2017) we show that in 2016 there were 29 patent owners that charged royalties in the smartphone production chain. Thus, $n = 29$. As can be seen in Figure 3, had each of the 29 patent holders acted as an independent profit-maximizing monopolist, as the royalty stacking conjecture posits, the aggregate royalty would have summed to 78 percent of the price of a smartphone. This would have driven up prices, such that the average selling price of a smartphone in 2016 would have been $1,364 instead of $298. At this higher price, only 47 million smartphones would have been sold, instead of 1.4 billion. The total revenues of the industry would have therefore been only $62 billion, instead of $425.1 billion—but, and this is key, the revenues of the 29 patent holders would have been more than three times higher--$48.5 billion, instead of $14.2 billion.

This technique also allows a researcher to test the hypothesis that the results that we actually observe—sales of 1.4 billion smartphones, at a price of $298, yielding total revenues of $425.1 billion—are the result of royalty stacking. As we show in Galetovic, Haber, and Zaretzki (2017), there is a way to generate the result that the royalty rate of 3.3 percent was the product of royalty stacking, but generating that result requires a researcher to assume that the elasticity of demand for smartphones in 2016 was 853. This is roughly 800 times higher than the elasticities of demand actually observed for consumer products. To see the full absurdity of this assumption, consider that an elasticity of demand of 853 implies that a ten percent decrease in the price of a smartphone would produce an 8,530 percent increase in the number of smartphones sold. We know, as an actual empirical fact that the price of a smartphone fell by 11 percent between 2013 and 2015, and that smartphone sales increased by 47 percent. One does not need algebra to show that the difference between 8,530 percent and 47 percent is very large.

3.2 Excessive royalties and additional market power

The problems with the bottom up technique go beyond its substitution of assumptions for empirics; there are deep conceptual flaws as well. Recall that the technique is posited as a solution to the problem of patent holdup and royalty stacking, and one of the core constructs of that theory is that SEP holders obtain market power from two sources. First, there is the (appropriate) market power that comes from the patent itself, as a function of the right to exclude. Second, there is the (additional) market power that its inclusion in an industry standard. The combination of the two produces an "excessive" royalty: the SEP holder is appropriating the value created by standardization, in addition to the value created by the patented technology.

As we explain in Galetovic and Haber (2017), there is a basic conceptual error in this formulation—the idea that standardization itself, independent of the technologies being standardized, creates value. Recall from Section 2 that value comes from products that do things that consumers value (e.g., a computer that allows a user to simultaneously play a movie, send an email, and write a document). A patented technology (or any input, for that matter) has value only if consumers obtain utility from, and therefore demand, its inclusion in the final good. Standardization permits those technologies to operate across multiple manufacturers and generations of the consumer product; it is necessary to realize the value created by the technology. It is precisely for this reason that it only pays to standardize technologies that do things that are valued by consumers; a standard for a useless technology is of no value at all. It follows that the value of standardization is not independent of the value of the technologies that have been standardized. Because they are not conceptually separable, their values cannot be determined independently of one another.

Let us illustrate this idea through a simple thought experiment. Imagine a consumer who has a choice between a computer that can send an email and a computer that cannot. The consumer will value the email-capable computer over the alternative, and one will be able to observe that price differential in the market. Now imagine that even though the computer can send an email, that email cannot be read by anyone else because there is not a standardized email protocol. From the point of view of the consumer, the patented email technology inside the computer would have zero value. Now flip the situation on its head. Imagine that there is a standard protocol for email, but that no computer company has developed a technology that allows computers to send an email. What value would consumers put on the standard? The answer, again, would be zero.

Conceptual errors tend to generate absurd implications, and the idea that one can separate the value of a patented technology from the value of the standard that it reads on is not an exception. The world is full of standards. Many are owned by multiple firms that both cooperate and compete with each in an SDO, but many are owned by a single firm whose technology is *the* de facto standard—Intel and its family of x86 processors being a canonical example. Once one holds to the proposition that it is possible to separate the value of a patented technology from the value of the standard on which reads, then the same logic about a technology firm appropriating the value of a standard must also apply to a single firm that emerged as the de facto standard. Both, after all, came about through a process of competition, and both are able to levy a monopoly price that is being passed along to consumers.

Let us consider the case of Intel in order to explore where this line of thinking leads. As is well known, during the first half of the 1980s several architectures competed with Intel for becoming the standard of the fledging, but rapidly developing, personal computer market. One of them was Motorola's 68000 processor, which many claim was technically superior to Intel's 8086. Another was the 6510 8-bit microprocessor produced by MOS Technology that powered the Commodore PC, which in the early 1980s was the main manufacturer of PCs. Intel's 8086 technology was, however, adopted by IBM when it decided to enter the PC market, and IBM did not constrain Intel from selling to its competitors. By virtue of being chosen by IBM, which had brand recognition and marketing capability, Intel's architecture became the dominant standard in the PC industry, and remains so to this day. Once it became possible to miniaturize the PC, Intel's family of x86 processors became the de facto standard for laptop computers when they began to emerge in the 1990s. A similar process occurred in the server-data center market, where Intel's family of x86 processors became the standard a bit later.

If one takes the logic underpinning the bottom up approach seriously, then one must conclude that Intel must be appropriating the value of standardization in the PC, notebook and server markets. Intel does not, of course, willingly license its technology, and therefore does not earn licensing royalties.[24] But that is irrelevant: the value of Intel's patented technologies is included in the price of its x86 CPUs. Should Intel now be forced to price its CPUs on the

[24] It does allow ARM to use its architecture under license, but that is a royalty-free license that Intel has disputed on multiple occasions.

basis of the price difference between its initial 8086 chip, the Motorola 68000, or the MOS 6510 at the time that all three were available in the market?

Underneath the absurdities generated by this line of thinking is a stylized story about how high technology products are created and improved. That story goes as follows: the creation of the patented technologies that allow a product to operate as advertised, the technical standards that allow those technologies to realize their potential in the market, and the manufacture of the consumer product that employs the standardized, patented technologies occur in discrete stages. This stylized story is necessary for patent holdup and royalty stacking theory to work, because unless one holds that there are discrete stages there would be no opportunity for the SEP holders to "hold up" manufacturers once they have invested and production has taken place. Like most stylized stories, however, this "stages" narrative bears little resemblance to what actually takes place in the creation of SEP-intensive, high technology products. What actually happens is that the patented technologies, the technical standards, and the consumer products that rely upon them co-evolve over time in an iterated and protracted manner. All of the players in the game—the technology development firms and the manufacturers—simultaneously compete and cooperate, and their cooperation takes place in the SDOs where they vote on the technical standards that make all of the products compatible and interoperable.

Asking what portion of the economic surplus created by consumer demand for a standardized technology is caused by standardization itself, and what portion is caused by the SEPs is akin to asking what portion of jackrabbit speed is due to the fact that coyotes hunt them, and what portion is due to the fact that jackrabbits live on flat, open terrain. For a biologist, this is a meaningless question: jackrabbits, coyotes, and the mixed shrub-grasslands that they inhabit co-evolved; each is an emergent property of a complex adaptive system that ecologists call a grassland ecosystem. So it is with patented technologies, technical standards, and the consumer products that require compatibility and interoperability: each is an emergent property of a complex adaptive system that economists call a market.

3.3 The flawed game theory behind the bottom up technique

Perhaps the proponents of patent holdup and royalty stacking theory, and the proponents of the "bottom up" technique of apportionment, are right? Perhaps there are unique stages of technology and product development, and thus the ability of SEP holders to set royalties "ex post," rather than "ex ante" is harmful? Let us therefore give that idea its due, and actually formalize it as a game.

In order to formalize the game one must first ask the question, "ex ante" to what? As Epstein, Kieff, and Spulber (2011) have pointed out the game that is implicit in Patent Holdup and Royalty Stacking theory posits three stages. In the first stage, an industry standard is chosen. In the second stage, manufacturers make investments. In the third stage, technology development firms charge royalties. "Ex ante" in this context means before industry standards are chosen.

As Epstein, Kieff, and Spulber (2011) have pointed out, there is no stage in which technology development firms invest! Patent holdup and royalty stacking theory—and thus the bottom up technique of apportionment—posits that at the moment when an industry standard is chosen there are many technologies available, which arrived like manna from heaven, each one pretty much the same as the others. It follows that had there been a competition among the various technologies in the first stage based on price, the technology development companies would have received almost nothing, because their opportunity cost to develop that technology was "insignificant." Consider the formulation in Leonard and Lopez (2014):

> For many SEPs, the owner likely had no significant opportunity cost to contributing to the standard but faced intense competition to be included in the standard. An important potential source of opportunity cost is if the patent owner had the ability to set up a proprietary alternative standard or organize an alternative SSO. However, few patent owners have such an ability and thus few patent owners face a significant opportunity cost of this type. For example, in the case of 802.11, there are too many technologies required for any one patent owner to be able to offer a proprietary alternative standard. For similar reasons, the competition between substitute technologies to be chosen for the standard would be expected to be intense. It would generally be a winner take- all proposition, with technologies not chosen for inclusion in the standard receiving no royalties in the technology area in question.

There is, of course, a basic problem with this formulation, which has been pointed out by Sidak (2013): technologies are the outcome of investments in R&D made in the expectation of profit. Thus, the claim that technologies are always abundant and should receive royalties close to zero assumes that technology developers will consistently invest in equilibrium in order to make negative expected returns is an absurdity.

Let us therefore formalize a four-stage game, in which there is a first stage in which technology development firms decide whether to enter an industry and invest in R&D. Let us also posit two variants of this game. In one variant of the game, royalty rates are set before the standard is chosen (the so-called "ex ante" competition that must be restored via the bottom up technique). We denote this as the Ex Ante variant. In the second variant of the game, royalty rates are set after the standard is chosen and the manufacturers have begun production (the so-called "ex post" setting of royalties that supposedly generates "patent holdup"). We denote this as the Ex Post variant.

Let us now see if it matters where the royalties are set. The formal argument is in the appendix; here we discuss the intuition. In the first stage of both variants, technology firms decide whether to enter the industry and invest in R&D. Crucially, as in any game, players backwards induct.

In both the Ex Ante and Ex Post variants of the game technology firms and manufacturers invest in equilibrium. In both variants, manufacturers pick the best technology as the standard. In both variants, technology firms and manufacturers make zero expected profits upon entry because they know that they are going to face competition—and they may lose.

There are, however, some important differences across the two variants of the game—but, and this is key, it is not clear which provides a better welfare outcome. In the Ex Post variant, the technology development company that comes up with the technology that is chosen as the standard makes larger profits than it does in the Ex Ante variant.[25] The reason is simple: because the royalties are set after the standard is chosen and manufacturers have invested, the winning technology development firm can charge the unconstrained monopoly royalty. This is not necessarily bad, however, because in the Ex Post variant of the game there is more innovation than in the Ex Ante variant of the game. Again, the reason is simple: everyone involved knew from the start that the winning technology development firm would receive a monopoly royalty; and thus in equilibrium there was more entry by technology development firms, more R&D, and more competition to become the standard. The result is more innovation.

What we learn from the two variants of the (properly specified) game is that there is a trade-off. In the Ex Post variant, there is more innovation but higher royalties. In the Ex Ante variant, there are lower royalties, but less innovation. Whether one or the other is better

[25] These are profits conditional on being the best technology. Upon entry, no firm knows whether its technology, or that of a competitor, will be the best. In expectation, all firms therefore make zero profits.

depends upon specific features of industries, such as the elasticity of the demand curve, the cost of doing R&D, and the cost of producing the final good. One thing that is clear, however: once investment in R&D is added to the game, it does not necessarily follow that establishing royalty rates ex post is harmful.

Several implications follow from this analysis. One is that there is no basis to the argument that the observation of profits earned by technology development firms is evidence of "excessive" market power. Another is that where royalties are set—either before a standard is chosen or after—should not matter to competition authorities: neither is unambiguously better in terms of welfare. Finally, the analysis negates the theoretical construct underneath the bottom up technique. If the welfare consequences are ambiguous, then it does not follow that restoring "ex ante" royalty setting generates an outcome that is "fair and reasonable."

3.4 Practical flaws

It is an irony that while the logic underpinning the bottom up approach has been widely embraced by competition authorities, the technique itself has never actually been applied. The reason can be readily understood if one reads the FTC's recommendation about its use with a bit of care.

> Courts should recognize that *when it can be determined*, [emphasis ours] the incremental value of the patented invention over the next-best alternative establishes the maximum amount that a willing licensee would pay in a hypothetical negotiation. Courts should not award reasonable royalty damages higher than this amount.

The fact is that "the incremental value of the patented invention over the next-best alternative" cannot be determined when the next-best alternative never came to market because it was not selected by an SDO into a standard. Plainly stated, no one can claim to know the market price of a technology that never sold in a market.

4. The top-down technique

The top-down technique is an attempt to deal with the fact that the bottom up technique cannot actually be operationalized.[26] The underlying theory—patent holdup and royalty stacking—is exactly the same. In fact, Contreras (2017) argues that the top down technique is needed because even a properly executed bottom up exercise might create royalty stacking. Because it based on a flawed theory, top down is as fraught as bottom up. In attempting to make that flawed theory operationalizable, however, the top down technique generates additional errors of reasoning.

As Leonard and Lopez (2014) explain it, the top-down is applied in two steps. First, a researcher determines the cumulative royalty that should be received by an entire suite of SEPs. Second, the researcher should use an algorithm to apportion a fraction of the cumulative royalty to the litigated patents.[27]

4.1 A pie of fixed size of unknown origin

The key error made in the top-down technique is that a researcher should find the cumulative royalty that SEP holders as a group *should charge* for the entire suite of SEPs. There seems to be agreement that the cumulative royalty should be limited to the incremental value of the invention that the parties would have agreed in an hypothetical ex ante negotiation.[28] As we have already discussed, this cannot be achieved.

[26] See, for example, Leonard and Lopez (2014) and Contreras (2017a, b). The top down technique has been used in Innovatio, Apple Japan v. Samsung, Unwired Planet v. Huawei and TCL v. Ericsson.
[27] See also Bailey et al. (2007).
[28] See, for example, Deng et al. (2018).

In practice, therefore, courts and experts have proposed a number of methods, all of which are more or less arbitrary.[29] In Innovatio (2013), for example, the court accepted an expert's opinion that the cumulative royalty paid by manufacturers of WiFi equipment using the IEEE's 802.11 standard should not exceed the profit per chip that embedded the standardized technologies. The court therefore estimated that the "right" royalty as equal to that profit margin: 12.1 percent of the price of a chip.[30] The court was explicit:

> In summary, the Top Down approach starts with the average price of a Wi-Fi chip. Based on that average price, [calculate] the average profit that a chipmaker earns on the sale of each chip, thereby isolating the portion of the income from the sale of the chip available to the chipmaker to pay royalties on intellectual property.

We hope that it is obvious to readers that this means that the court posited that there is a fixed pie of revenue at each stage of a production chain that is independent and separable from the rest of the chain. The court assumed that value comes from WiFi equipment, rather than from the consumer demand for the ability to communicate using smartphones, computers, and tablets that make use of WiFi technologies. In short, the court made engaged in an exercise that violated a key tenet of price theory: total revenues in an industry are bounded by the demand curve, and producers at any stage of a production chain will endogenously adjust their prices and output in accordance with the signals they receive from producers at other stages of the production chain (as well as signals that they receive from competitors).[31]

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[29] An exception is Sidak and Skog (2017), who use a hedonic regression to estimate the incremental value of the technologies embedded in the LRDIMM 4 standard over the technologies embedded in the previous version on the standards *and which were still available in the market*. Contrary to the methods that have been used by courts, therefore, this one is based on an explicit and established theory of value: in a market's equilibrium, differential prices embedding different technologies are equal to consumers' differential willingness to pay at the margin for the best technology. Moreover, so far this is the only method that relies on observable market transactions and prices to estimate the value of the cumulative royalty.

[30] See Innovatio (2013, pp. 84-85)

[31] Other examples include Samsung v. Apple Japan, where the Japanese Intellectual Property High Court held that the cumulative royalty for the 3G UMTS should be 5 percent; Unwired Planet v. Huawei; where the court used announcement made by some patent holders about the cumulative royalties they expected to see; and TCL v. Ericsson, where courts followed the same method as in Unwired Planet. See Contreras (2017, pp. 11, 693), Ericsson (2008), and Deng et. al., (2018).

Some antitrust authorities and the IEEE have carried this thinking about separable and independent stages of production chains to its logical conclusion by arguing that patent holdup and royalty stacking can be stemmed by forcing SEP holders to pick the smallest saleable patent practicing unit (SSPPU) as the royalty base.[32] Applied in this way, this is a variant or complement of the top down technique: the SSPPU is to cap the royalty that a SEP holder can charge. As Bailey et al (2011) argue, this SSPPU variant of top down apportionment makes no sense:

> […]consider a patent related to a microprocessor incorporated into mobile phones. A chip that provided some improvement (in speed, efficiency, etc.) may enable other functionality on the phone, such as an improved touchscreen interface, software applications with greater capability, greater video functionality, or improvement of other features of the phone. While apportionment would recommend that the royalty base be limited to the chip "portion" of the phone, this delineation may miss synergies between the patent at issue and the other features of the mobile phone. It would be incorrect to attribute all such synergies to the infringing company (or, for that matter, the patented feature).

Ultimately, the top down technique starts with a fundamental fallacy: a single expert or court is in a position to determine the combined value created by all patented technologies in a standard, and then is in a position to apportion that value across all the individual patents. That fallacy requires the court to embrace a second fallacy: the expert is in a position to determine how much of the total revenues generated by a market should be allocated to each of the firms in the production chain, not only including the firms that generated the patented technologies, but the implementers as well. This is a rather extraordinary claim; it requires the court to embrace the idea that the expert is in a position to determine, for example, the appropriate profit margin of every firm in the production chain of a complex product, including the implementers at the end of the chain. Thus, in so far as the top down technique

[32] For critical assessments of the SSPPU see Kappos and Michel (2017) and Gautier and Petit (2018).

can be linked to markets determining the value of a technology, the underlying assumption seems to be that the feedbacks that characterize markets are easily replicated using simple algorithms. There is no body of evidence that supports this view.

4.2 Conceptual and practical flaws of apportionment exercises

The second step of the top down technique is to use some algorithm to allocate the cumulative royalty to particular SEP portfolios or even individual SEPs. It is not clear, however, how a court should apportion the aggregate value of the standard among its component patents. A number of methods have been proposed and used by courts and experts.

Some courts have simply accepted an estimate of the number of SEPs and calculated the share of the SEP holder in the total. For example, in Samsung v. Apple Japan the Japanese Intellectual Property High Court used a research report that claimed that there were 529 patent families involved, and then calculated Samsung's share. In TCL v. Ericsson the court determined the value of Ericsson's SEPs as a percentage of the total number of SEPs claimed to be relevant. That is, the court decided that all SEPs were the essentially of equal value.

Some experts have argued that not all patents are equally valuable and have proposed methods to estimate the differential value of each SEP, but these approaches are also fraught.[33] Thus, for example, in Innovatio (2013), the court accepted an expert's opinion that not all patents were equally valuable and that "[…] the top 10% of all electronics patents account for 84% of the value in all electronics patents." The expert obtained this number, however, from a 1998 paper that estimated the distribution of value of all French patents granted in 1970, using information from patent renewals in France between 1969 and 1982.[34]

[33] See, for example, Leonard and Lopez (2014).
[34] See Schankerman (1998).

The court then allocated the share of the cumulative royalty by making a judgement about the importance of Innovatio's patents by assuming that they were in the top ten percent of all 802.11 standard essential patents. In Unwired Planet v. Huawei experts proposed to apportion the cumulative royalty based on quality-adjusted patent counts, where quality was measured based on the number of contributions to the standard setting process.[35] Sidak and Skog (2017) have proposed to apportion value with a weighted index of SEPs forward citations.

There is no shortage of metrics by which to apportion the value of all SEPs to a particular firm, and they differ. None, however, is based on any theory of economics that we know of.

Consider, for example, the claim that a patent's share in a citation-weighted index is a good proxy for its share in an aggregate market royalty. There are some empirical papers that link forward citations with different measures of patent value, but these studies are rather tentative.[36] Hall et. al, (2005), for example, finds that R^2s on the order of 0.1 and 0.3, meaning that the predicted values are very noisy. The reason for their limited value is that there exists no theory explaining the link between the number of forward citations and the value created by the technology claimed by the SEP. As Katznelson (2007, p. 20) explains, a patent is cited in order to limit the scope of the claims of the citing patent. The citations are unrelated to the value that consumers may assign to the technologies associated with the cited patent.

Apportionment methods, in fact, have so many practical flaws as to render the exercises meaningless. There is not even agreement on what a SEP is, and how many patents

[35] See Deng et al. (2018, fn. 19). Huawei used a counting technique called "Huawei Patent Analysis" (HPA). Unwired Planet's patent counting method is called the Modified Numeric Proportionality Approach (MNPA). See Unwired Planet v. Huawei at §199.

[36] See, for example, Trachtenberg (1990) on the relation between citation counts and social surplus created by a patented technology; Giummo (2003), who found that the royalties received by inventor/patent holders at nine major German corporations under the German Employee Compensation Act of 1957 correlated positively with the number of forward citations received by the patent and; Hall et al. (2005) on the relation between the number of forward citations and a firms' stock market value.

are truly SEPs. Mallinson (2011), for example, compared two studies commissioned by industry participants that purported to count the number of essential patent families owned by major SEP holders in mobile phones. One study claimed to have relied on "[…] industry experts that included physics PhDs, wireless engineers, patent legal specialists, and former patent office employees." The other study claimed to have accumulated six years of experience assessing essentiality. If determining essentiality were an exact science, both studies should have allocated the same number and share of SEPs to each patent holder and a plot of the data in a two-dimensional graph should have accumulated data points on a 45° line. Mallinson found, however, that the correlation between both studies was exactly zero. Mallinson (2017) added six more studies to his original two, and found that the correlation between pairs was generally below .5. It should not come as a surprise that when firms bargain over royalties they do not engage in patent counting: they agree on royalties to license an entire portfolio, without distinguishing between SEPs and non SEPs and without doing a patent-by-patent assessment.

4.3 *Can the top down technique be saved?*

Is there any way to give theoretical coherence to the top-down technique of apportionment? There is one, but it requires the assumption that patents are nothing more than a license to charge a private tax; the technologies they cover do not contribute value.[37] The level of the tax and its apportionment would be the result of political bargaining, not the work of market forces. Any apportionment rule would therefore be based not on any economic theory at all, but on the distribution of political power.

[37] Indeed, many authors and firms talk about the "royalty burden," a term very much alike to "excess burden," which denotes the net welfare loss wrought by a distortionary tax.

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Figure 1
Value and distribution in the smartphone production chain, 2016

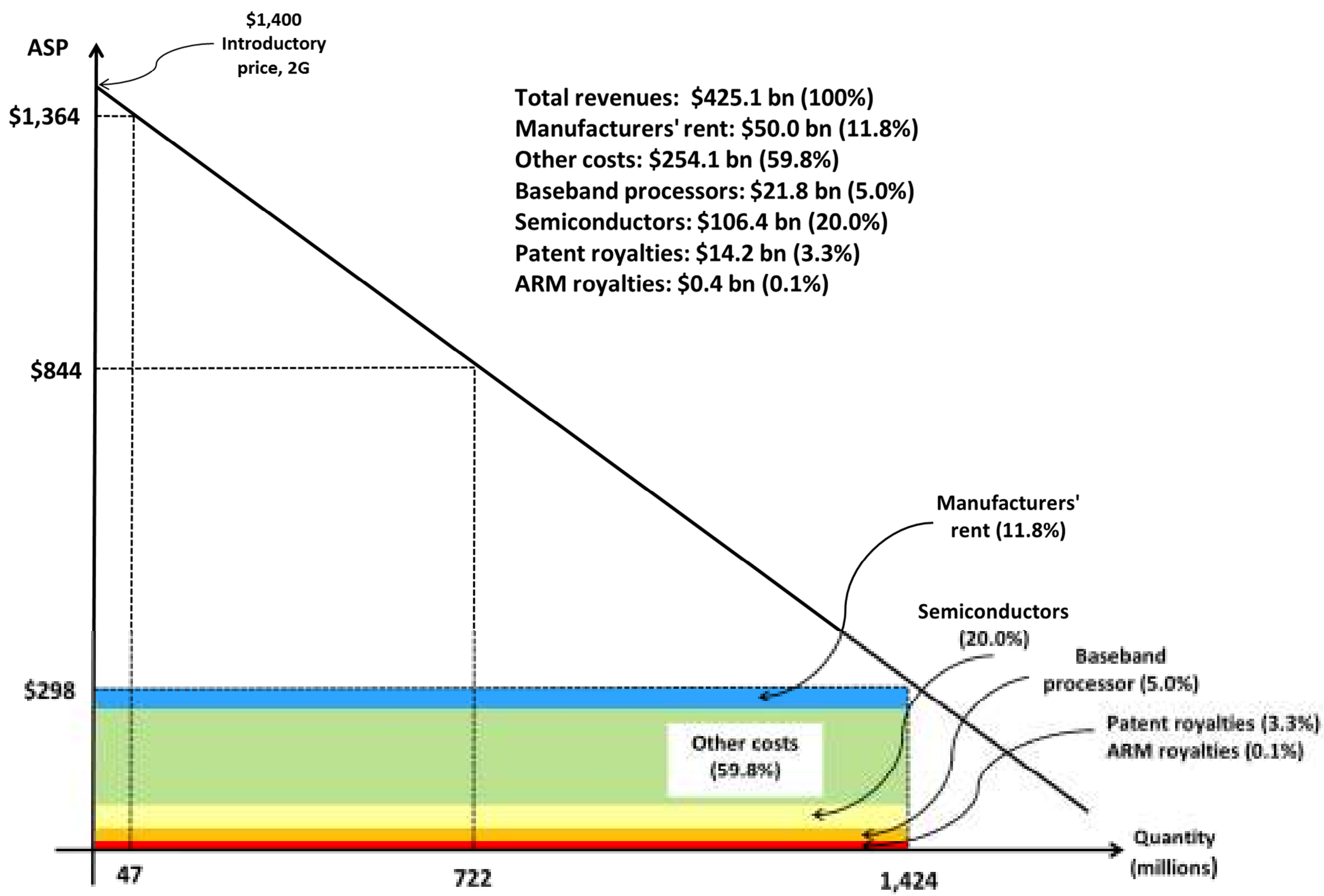

Figure 2
Value and distribution with an hypothetical patent monopoly in the smartphone production chain, 2016

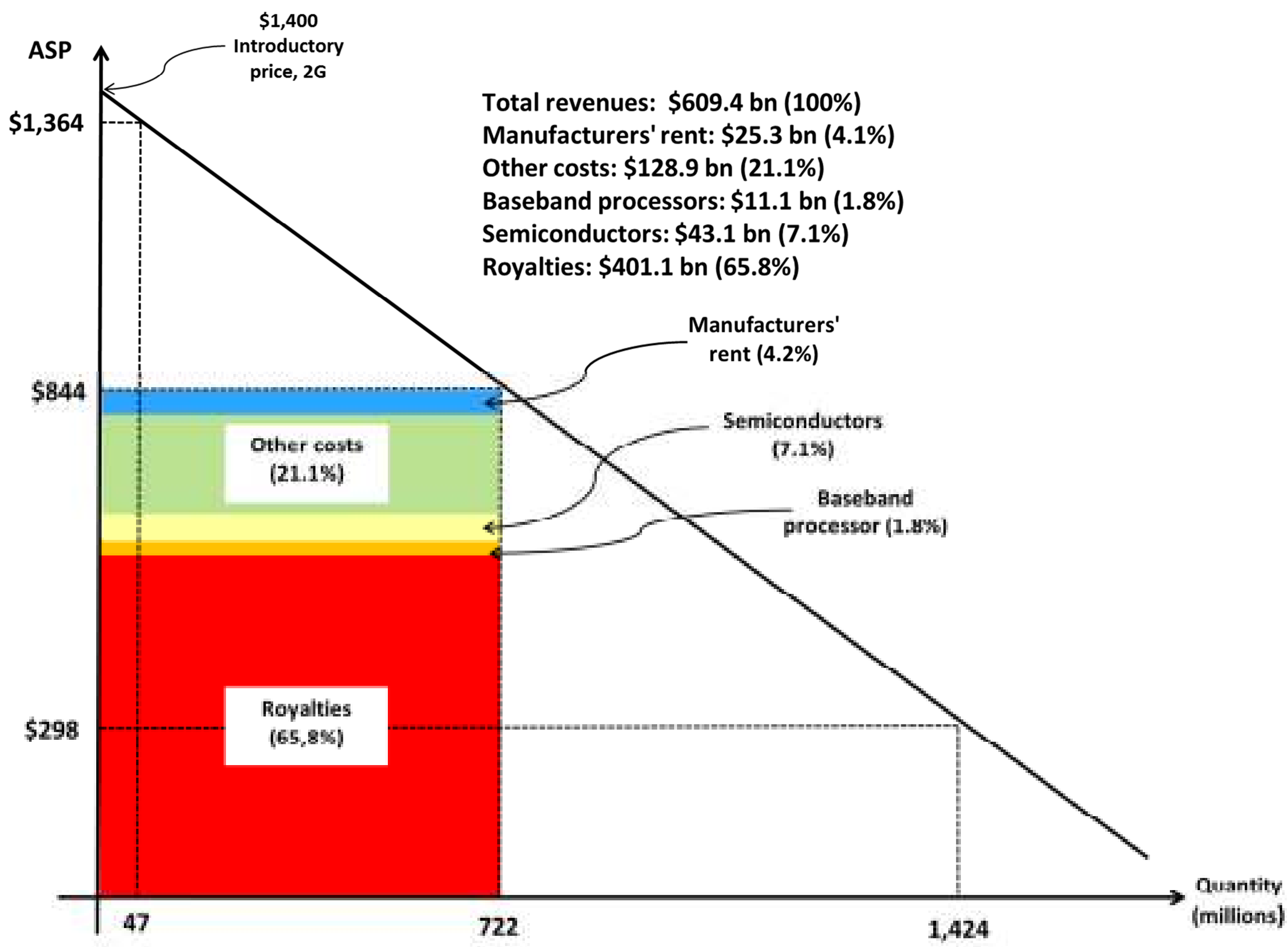

Figure 3: Patent royalties as percentage of the value of mobile (smart and feature) phones shipped, 2007-2016

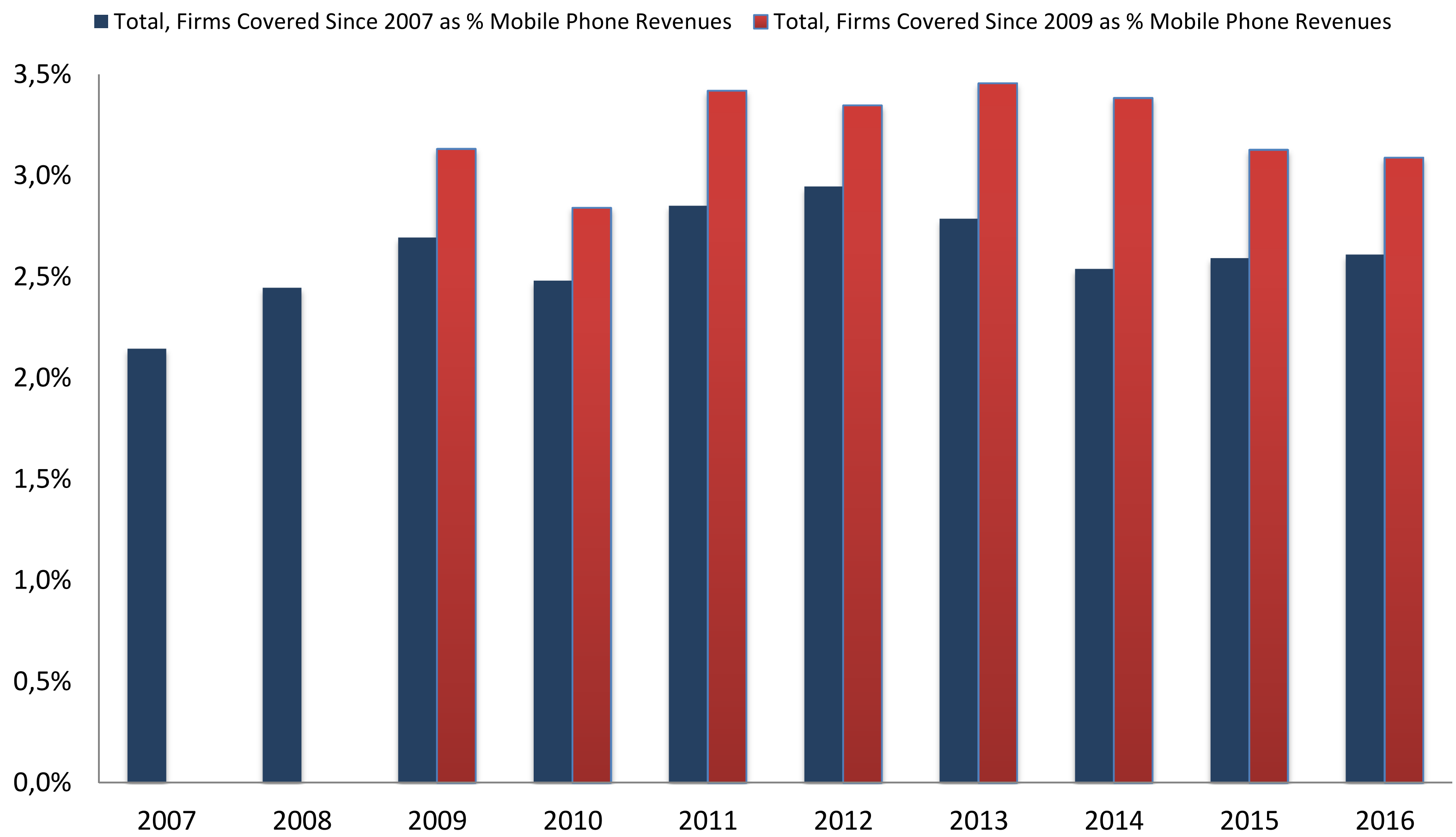

Figure 4: The composition of mobile (smart and feature) phone revenues, 2007-2016

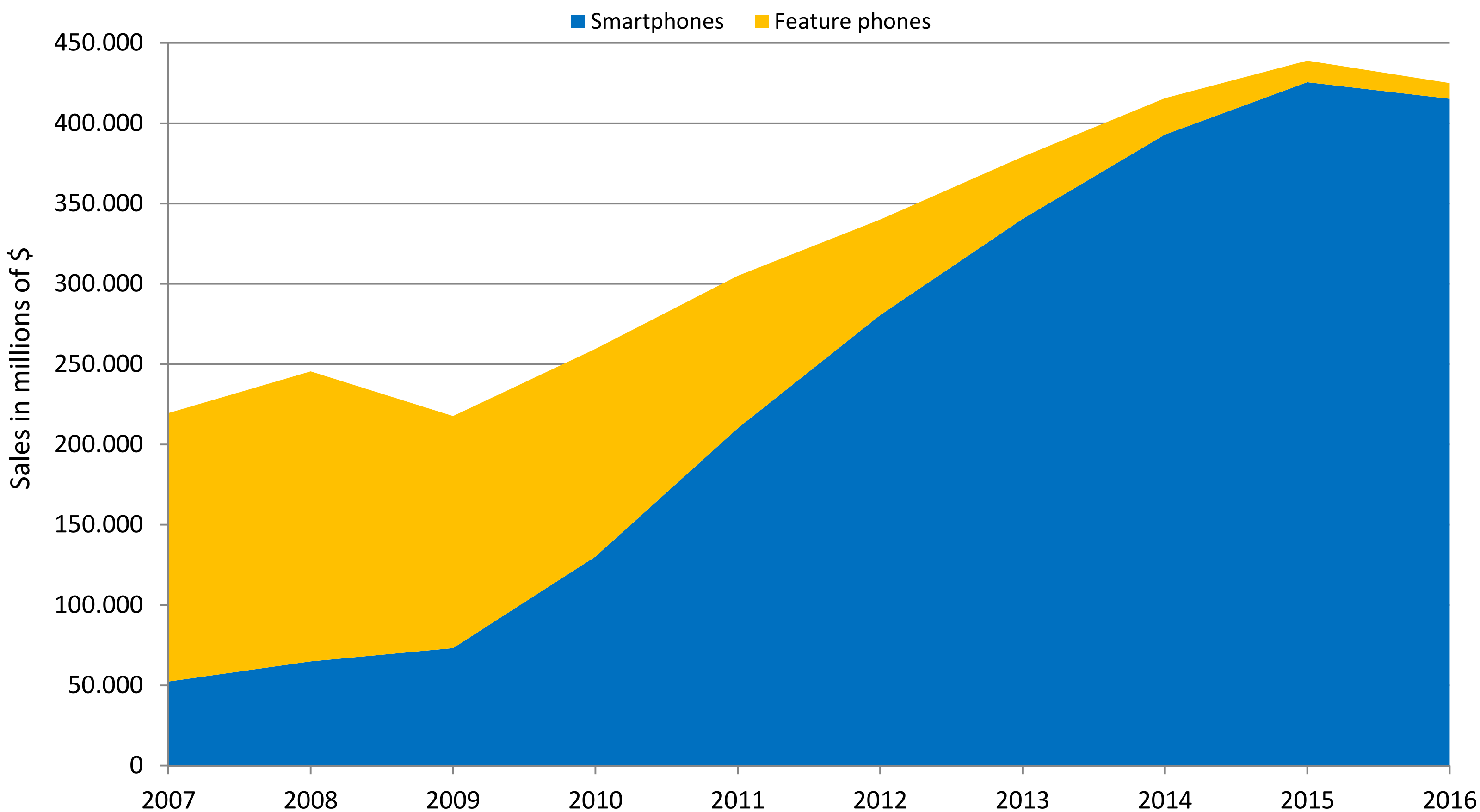

Figure 5
Value and distribution with royalty stacking in the smartphone production chain, 2016