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ABSTRACT

Royalty Stacking in High Tech Industries: Separating Myth from Reality*

A few recent contributions have claimed that in high-tech industries – where innovation is often cumulative and products include many components which are protected by patents in the hands of many different patent holders – the cost of obtaining all necessary licenses is too high. Some have even requested sweeping policy reforms to deal with the so-called royalty stacking problem. In this Essay we find that the empirical evidence – including new evidence for the 3G telecom industry – does not corroborate the gloomy predictions of the proponents of the royalty stacking hypothesis. A careful look at the theoretical underpinnings of this hypothesis explains the lack of empirical support. First, three necessary conditions must be satisfied for a royalty stacking problem to exist: (a) innovation must be cumulative, so that the patents are complementary; (b) there must be many patents for a given product; and (c) the many patents must be held by numerous, distinct rights holders. Second, royalty stacking may not be a problem even if the three necessary conditions are met; i.e., the three necessary conditions are not sufficient. And, third, several market mechanisms, such as cross licensing or voluntary patent pools, can be used to mitigate the costs of multiple concurrent patent negotiations. We conclude that the so-called royalty stacking problem is more myth than reality and that there is no reason to adopt the dramatic reforms in antitrust and patent law that have been recently proposed by, inter alia, Lemley and Shapiro (2006).

JEL Classification: L13, L96 and O34
Keywords: excessive royalties, hold up, innovation, mobile telecommunications and patent licensing

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I. INTRODUCTION

Royalty stacking, patent hold-ups, patent thickets, patent holdouts, anti-commons—all manner of theories have been posited regarding the potentially adverse effects of the very real trend for ever increasing patenting in high technology fields. The central premise behind all of these gloomy propositions is that as more and more firms take out patents on their inventions, it gets more and more difficult for those that come after them to innovate and compete. That is, sequential innovators operating at the same level of the vertical chain or downstream manufacturers relying on their technologies have more trouble completing any incremental improvements or commercializing products reliant on the technology because they must first gain access to the earlier patent rights.

The economic logic supporting this premise is related to the so-called "complements problem" first studied by the French engineer Augustin Cournot in 1838.[2] Cournot showed that consumers are better off when all products that are complementary from a demand viewpoint are produced and marketed by a single firm. In the context of high-tech industries, the complements problem would operate as follows. Consider a high-tech product (e.g., a mobile phone, a game console or a computer) incorporating multiple innovations, all of which are protected by patents. Suppose, in addition, that each of those patents is owned by a different patent holder. From the perspective of a manufacturing company seeking to develop and commercialise that product, all those patents are strict complements: the company needs to obtain licenses for all of them in order to avoid the risk of being sued for patent infringement and the subsequent risk of abrupt termination of business. The difficulty is that the company faces multiple gatekeepers, each of whom must grant a license before the product can be legally commercialised. It is argued that when each of those gatekeepers (patent holders) considers which royalty rate to charge (among

[2] Cournot, Augustin. 1838. Recherches sur les Principles Mathématiques de la Théorie des Richesses. Paris: Hachette. English edition (ed. N. Bacon): *Researches into the Mathematical Principles of the Theory of Wealth*. New York: Macmillan, 1987.

other terms to be negotiated in a license agreement),[3] it may not fully take into account that an increase in its royalty is likely to result in a cumulative royalty rate that may be too high according to both the licensee and the other patent holders. Since each patent holder is likely to ignore the negative externality caused by its own pricing policies, so the argument goes, the aggregate royalty fee for licensing all of the required pieces may add up to a very large amount—perhaps so large that it is no longer economical for the manufacturing company to develop and commercialize the product. Licensees would be better off if all those licenses were consolidated under the control of a single patent holder acting on behalf of the group as a whole.

Relying on this logic, some authors have claimed that in high-tech industries—which are typically characterised by cumulative innovation and dispersed ownership of patents—the cost of obtaining all necessary licenses is too high. They sustain that, as a result, innovation has been thwarted and consumers have been harmed.[4] Furthermore, they argue that market-driven mechanisms, such as cross licensing, patent pools and patent platforms, are unlikely to completely solve this royalty stacking problem, especially in industries such as telecommunications and computing where new technologies frequently develop under the auspices of standard setting organizations.[5]

Those authors have proposed alternative ways to navigate the "patent thicket". All the proposals involve some degree of regulatory and policy reform. For example, it has been argued that the rules and procedures of standard setting organizations should be modified to constrain the ability of intellectual property (IP) holders to charge "excessive" royalties. Proposals have, for instance, called for firms that hold patents they consider essential to a potential standard to disclose their

[3] License agreements can contain any number of financial and non-financial terms, including upfront payments, milestone payments, royalties, exclusivity terms, etc. We use royalty rate in this paper as a short hand for all of these licensing terms.
[4] See, e.g., Thomas D. Kiley, "Patents on Random Complementary DNA Fragments?", *Science* 257, no. 5072, August 1992, p. 916-917; Michael Heller and Rebecca Eisenberg, "Can Patents Deter Innovation? The Anticommons in Biomedical Research," *Science* 280, 1998: 698-701. This article was based on a more formal analysis by Michael Heller in "The Tragedy of the Anticommons: Property in the Transition from Marx to Markets," *Harvard Law Review*, vol. 111, 1998; Carl Shapiro, "Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard-Setting," in *Innovation Policy and the Economy*, Volume I, Adam Jaffe, Joshua Lerner, and Scott Stern, eds., MIT Press, 2001; and Mark Lemley and Carl Shapiro, "Patent Holdup and Royalty Stacking", Working paper, 31 May 2006.
[5] Shapiro, *supra* note 4.

licensing terms prior to the adoption of the standard.[6] Others have suggested that antitrust authorities should take a lenient approach to collective negotiations of licensing terms before a standard is adopted.[7] In a notable paper, Swanson and Baumol suggest that during the development phase of a standard, standard setting organizations might hold an auction whereby IP rights holders vying to have their technology incorporated in the standard would submit offers to license that technology downstream in addition to touting their technological specifications.[8] More recently, a few authors have proposed limiting the right of patent holders to seek injunctive relief for patent infringement in high-tech industries.[9] Giving up the right to injunctive relief would reduce the bargaining power of the patent holders and cut down royalty rates. But it would also *increase* incentives for costly patent litigation, to the extent that injunctions act as a deterrent to patent infringement.

In sharp contrast, other authors consider the recent criticism of the growth and increasing fragmentation of IP rights in high technology industries as exaggerated and the proposed reforms as unwarranted and potentially harmful.[10] First, enforcing intellectual property rights is difficult and costly and, in consequence, the protection afforded by those rights is more limited in reality than on paper.[11] Second, most patent holders have powerful incentives to license their technologies at "reasonable" royalty rates before their patents expire.[12] Patents depreciate quickly and any outright or constructive refusal to deal involves a significant opportunity cost. Finally, given the intangible nature of information, granting a right and actually enforcing it may

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[6] See e.g., Marc Hansen, Gil Ohana, & Omar Shah, "Disclosure and Negotiation of Licensing Terms Prior to Adoption of Industry Standards: Preventing Another Patent Ambush," *European Competition Law Review*, vol. 24, 2003; For more on these arguments see, Damien Geradin and Miguel Rato, "Can Standard-Setting lead to Exploitative Abuse? A Dissonant View on Patent Hold-Up, Royalty Stacking and the Meaning of FRAND", Working Paper, November 2006. Available at: http://ssrn.com/abstract=946792.

[7] See, e.g., Robert Skitol, "Concerted Buying Power: Its Potential for Addressing the Patent Holdup Problem in Standard-Setting", *Antitrust Law Journal*, vol. 72, 2005..

[8] Daniel G.Swanson and William J. Baumol, "Reasonable and Nondiscriminatory (RAND) Royalties, Standards Selection, and Control of Market Power," *Antitrust Law Journal*, vol. 73, 2005, pp. 15 – 21.

[9] Lemley and Shapiro, *supra* note 4; Mark Lemley, "Ten Things to Do About Patent Holdup of Standards (and One Not to)," Working paper 2006, p.6..

[10] See, e.g., R. Polk Wagner, "Information Wants to be Free: Intellectual Property and the Mythologies of Control," *Columbia Law Review*, vol. 1, 2003; Richard A. Epstein and Bruce N. Kuhlik, "Is There a Biomedical Anticommons?" *Regulation*, Summer 2004; David Adelman, "A Fallacy of the Commons in Biotech Patent Policy" *Berkeley Technology Law Journal*, vol. 20, 2005.

[11] Wagner *supra* note 10, at p. 1011

[12] Epstein and Kuhlik *supra* note 10, at p. 55.

encourage rather than deter sequential innovation in the long term.[13] This is because the innovation protected—expression in the case of copyrights or novel inventions in the case of patents—cannot be entirely withdrawn from the public domain, much less in the long term. By increasing the incentives to invest and produce new information goods and technologies, intellectual property rights will eventually also lead to more and more valuable "open" information.

The empirical literature testing the validity of the royalty stacking and anti-commons theories in the real world is sparse and often not very rigorous. More importantly, the existing evidence is mixed. Researchers have found a possible and limited royalty stacking effect in the software industry,[14] a possible effect in the semiconductor industry,[15] though apparently mitigated through market mechanisms (cross-licensing), and no systematic effect in the biomedical industry.[16] Lemley and Shapiro (2006) have recently argued, relying on purely anecdotal evidence, that a royalty stacking problem exists in the development of the WCDMA (a 3G mobile telephony technology) and WiFi (a technology for wireless local area networking) standards.

We first investigate whether there is indeed evidence of a royalty stacking problem in the 3G cellular telecom industry. We employ a simple econometric model developed by Noel and Schankerman (2006) to analyze the software industry.[17] This model tests whether the market value of a company producing high-tech products embedding multiple innovations protected by patents is affected by the degree of concentration of those patent rights. If the answer is negative—i.e., if there is no statistically and/or economically significant relationship between the company's

[13] Wagner *supra* note 10; Ashish Arora, " Contracting for tacit knowledge: the provision of technical services in technology licensing contracts,". *Journal of Development Economics*, Vol. 50 (1996), p. 233-256.
[14] See Mark Schankerman and Michael Noel, "Strategic Patenting and Software Innovation," CEPR Discussion Paper #5701, June 2006. Available at www.cepr.org/pubs/dps/DP5701.asp.
[15] Bronwyn H. Hall and Rosemarie Ham Ziedonis, "The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 1979-1995," *RAND Journal of Economics*, vol. 32 no. 1, Spring 2001, Rosemarie Ham Ziedonis, "Don't Fence Me In: Fragmented Markets For Technology And The Patent Acquisition Strategies Of Firms", *Management Science* 50(6), 2004: 804-820.
[16] John P. Walsh, Ashish Arora, and Wesley M. Cohen, "Effects of Research Tool Patents and Licensing on Biomedical Innovation," in W.A. Cohen and S.A. Merrill (eds.): *Patents in the Knowledge-Based Economy* Washington, D.C., National Academies Press (2003), Epstein and Kuhlik *supra* note 10.
[17] They, in turn, base their model on one developed in Nicholas Bloom, Mark Schankerman, and John Van Reenen, "Identifying Technology Spillovers and Product Market Rivalry," CEPR Discussion Papers 4912, 2005.

market value and the fragmentation of the IP rights—then the royalty stacking hypothesis is rejected. If, instead, there is a significant and material negative relationship, the model indicates a possible royalty stacking problem. In this last case, however, the evidence is not conclusive, since the negative impact on market value may not be due to an excessive cumulative royalty rate but to the transaction costs of having to negotiate with multiple patent holders.

The results of our econometric analysis do not support those who claim the existence of a serious royalty stacking problem in the 3G telecoms industry. If royalty stacking were a significant problem in the industry, firms with downstream operations would be negatively affected. But we find no clear evidence of such a problem for operators, upstream or vertically integrated firms. Under various model specifications, we find one consistent phenomenon. The effect of citation concentration is positive among upstream and vertically integrated firms, but never significantly so. The effects of technology spillovers are not found to be significant either. Rivals' patenting does have a statistically significant negative effect on vertically integrated firms, but the effect is not significant for the other two firm types.

Given the lack of empirical support, we return to the theory in order to determine under which conditions we should expect an industry to exhibit a royalty stacking problem. The literature has shown that three conditions are *necessary*: First, innovation must be cumulative, so that the patents are complementary. Second, there must be many patents for a given product. Third, the many patents must be held by numerous, distinct rights holders. If one of those conditions were not satisfied, the magnitude of the royalty stacking problem would be minimal or, even if potentially significant it could be resolved through a limited number of bilateral negotiations. The literature has also shown that, even if those three conditions were satisfied, any royalty stacking problem could be mitigated, and possibly resolved, via cross licensing or through the establishment of a voluntary patent pool. We show that the three necessary conditions listed above are not *sufficient*. That is, royalty stacking may not be a problem even if the three necessary conditions are met (and even in the absence of mitigating institutions, such as patent pools). The assumptions required to obtain royalty stacking as the unique equilibrium of the bargaining game between IP holders and users are restrictive. Relaxing those assumptions weaken or eliminate the royalty stacking predictions.

The remainder of this paper is structured as follows. In Section II we provide a brief tour of the theoretical and empirical literature that has analyzed the effects of sequential, cumulative, and complementary intellectual property rights on innovation and welfare—from the tragedy of the anti-commons to the royalty stacking theory. In Section III we present the results of our empirical investigation of the 3G cellular telecom industry. In Section IV we revisit the royalty stacking theory to understand when it is likely to hold in practice. The theoretical insights developed in this Section are then used to interpret the empirical findings on the 3G telecom industry described in Section III. Section V concludes with a discussion of the policy implications of our empirical and theoretical results.

II. ROYALTY STACKING: AN OVERVIEW OF THEORY AND EVIDENCE

The roots of the royalty stacking proposition can be traced back at least fifteen years.[18] Scotchmer (1991) considered whether and how intellectual property policy should be adapted to reflect the fact that in many fields innovation is sequential and cumulative.[19] Because today's research is launched from the shoulders of yesterday's giants, patent law must be designed to maintain innovation over the long term:

> The challenge is to reward early innovators fully for the technological foundations they provide to later innovators, but to reward later

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[18] 1991 is, of course, an artificial cut-off. A large literature before Scotchmer (1991) discussed follow-on research, but many of these frameworks were simple two-period models, where the follow-on research was for a direct improvement to the original invention. Kitch (1977) is a seminal paper, arguing that patents represent prospecting claims to the follow on research in a particular area. Edmund W. Kitch, "The Nature and Function of the Patent System," *The Journal of Law and Economics*, vol. 20, October 1977. Just one year before Scotchmer (1991), Merges and Nelson (1990) observed that in a number of industries "technical advance is cumulative, in the sense that today's advances build on and interact with many other features of existing technology." Robert P. Merges and Richard R. Nelson, "On the Complex Economics of Patent Scope," *Columbia Law Review*, vol. 839, May 1990, p. 881.

[19] Suzanne Scotchmer, "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law," *Journal of Economic Perspectives*, vol. 5 no. 1, Winter 1991.

> innovators adequately for their improvements and new products as well.[20]

Scotchmer focused on patent rules as a means to strike that balance. If patent rights are over-protective, this may result in inefficient monopoly pricing, over-investment in R&D as firms race to be the patent "winner" with the big reward, and under-investment in follow-on research since patent infringement is hard to avoid. The first innovators need sufficiently strong rights to set correct incentives to induce their pioneering work, but enough profit potential needs to remain for second innovators so that they will invest if it is efficient for them to do so.[21]

This line of thought extends to a number of related theories predicting detrimental effects from patenting in industries with cumulative and sequential innovation, including many high technology industries, such as biotechnology, computer software, and telecommunications. The remainder of this section summarizes the literature that has built on the implications of cumulative and sequential innovation.

A. The Tragedy of the Anti-Commons

One of the earliest applications of the cumulative and sequential innovation theory was aimed at biotechnology research. In an article evaluating the National Institute of Health's (NIH) proposal to patent products resulting from sequencing the human genome, Kiley (1992) argued

> [b]ecause every step along the way draws another patent application, the path toward public possession of real benefit is increasingly obscured by dense thickets of intersecting, overlapping, and cross-blocking patents. …The cumulative royalty obligations threatens to have [a stunting] effect in biotechnology.[22]

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[20] Id, p. 30.

[21] Scotchmer pursued this line of reasoning in a later paper coauthored by Jerry Green. In that article, the authors considered whether follow on research was concentrated in one firm as opposed to undertaken by multiple different firms. They find that patent rights should last longer when the sequential efforts are *not* concentrated in one firm. Jerry R. Green and Suzanne Scotchmer, "On the division of profit in sequential innovation," *RAND Journal of Economics*, vol. 26 no. 1, Spring 1995.

[22] Kiley *supra* note 4, p. 916-917.

The articles that attached the "anti-commons" label to this "stunting effect" came several years later. Heller and Eisenberg (1998), reasoning along the same lines as Kiley, suggest that the combination of pioneer and follow-on inventors could lead to "too many" patents in biomedical research, ending in a "tragedy of the anti-commons."[23] The tragedy of the commons is a well known problem in joint ownership, when multiple owners share some property (like a village commons on which sheep will graze) and no one has the right to exclude any one else. The tragedy occurs from overuse—the villagers let their sheep graze too much, so that the field is completely destroyed.[24] The tragedy of the anti-commons is the mirror image of its better known cousin. When multiple owners share the rights to property but every one of them has the right to exclude all others, the tragedy occurs from under-use. Heller (1998) used the analogy of empty store fronts in Moscow post-Communist rule. The fragmented and bureaucratic nature of retail property ownership in Moscow makes it difficult for would-be entrepreneurs to obtain a lease and open shop. So instead, the stores sit empty while shop-keepers set up on the sidewalks using a system of temporary kiosks.

Heller and Eisenberg argue that an anti-commons tragedy could develop in biomedical research via one of two paths. First, the privatization of biomedical research through patenting might create "too many concurrent fragments of intellectual property rights in potential future products." Alternatively, patent policy might permit "too many upstream patent owners to stack licenses on top of the future discoveries of downstream users."[25] Even the language these authors use foreshadows the royalty stacking strand of the theory.

An anti-commons is not a foregone conclusion, however, even in the face of "too many" patents. Heller and Eisenberg observe that "[w]hen the background legal rules threaten to waste resources, people often rearrange rights sensibly and create order through private arrangements."[26] They point to institutions that have emerged

[23] Heller and Eisenberg *supra* note 4. This article was based on a more formal analysis by Michael Heller in "The Tragedy of the Anti-commons: Property in the Transition from Marx to Markets," *Harvard Law Review*, vol. 111, 1998.
[24] Garret Hardin, "The Tragedy of the Commons," *Science*, 162(1968):1243-1248.
[25] Heller & Eisenberg *supra* note 4, at p. 699.
[26] Id, 700.

within communities of IP owners who deal with one another on a recurring basis, such as copyright collectives in the music industry and patent pools in various manufacturing industries.[27]

Whether the proliferation of rights leads to a tragedy or not hinges on three factors, according to Heller and Eisenberg. Transaction costs are at the top of their list. If it is difficult or costly to bundle rights, then it is less likely they will be bundled. This might result, for instance, if the universities involved in biomedical R&D have little capacity to absorb the costs of licensing negotiations. Diversity of interests among rights holders is another obstacle. Certain national labs, such as the NIH, view their public health mission as demanding the widest distribution possible of all research findings. That goal dictates as low a royalty rate as possible. Private firms, on the other hand, are more likely to want to maximize royalty income, or set license fees so as to protect their market share for downstream products. Likewise, firms that pursue end-product development (i.e., vertically integrated firms) and firms that focus primarily on upstream R&D are also likely to be at odds when it comes to coordinating their rights. When rights holders have diverse interests it can be more difficult for them to agree on rights pooling mechanisms—such as patent pools—and thus a tragedy of the anti-commons might be more likely.[28] Finally, Heller and Eisenberg note that cognitive biases can interfere with licensing. They argue that biomedical research firms might tend to overvalue their discoveries, making the cumulative royalty rate for downstream firms too high in the aggregate. Unrealistically optimistic expectations, therefore, might inhibit the bundling of rights and thus increase the odds of a tragedy of the anti-commons.

The anti-commons claims have not gone unchallenged. Wagner (2003) disputes the suggestion that intellectual property rights are detrimental to “the continued flourishing of a public domain of ideas and information”.[29] Two key points that the anti-commons theory forgets, according to Wagner, are (a) the difference

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[27] Note that patent pools do not provide a silver bullet for an anti-commons problem. Pool participation is voluntary and firms with different business models can view the benefits of joining quite differently. See Anne Layne-Farrar and Josh Lerner, “To Join or Not to Join: Examining Patent Pool Participation and Rent Sharing Rules”, Working Paper, October 2006, available online at http://ssrn.com/abstract=945189..

[28] Id.

[29] Wagner, *supra* note 10.

between physical property and intellectual property and (b) the difference between the short-term and the long-term.

The theory of the anti-commons, as well as other related criticisms of intellectual property rights understate the significance of the intangible nature of information, and thus overlook the contribution that even perfectly controlled intellectual creations make to the public domain.[30] For example, a patent on a particular form of hybrid corn may prevent other agribusinesses from exactly copying the corn, but they can learn the value of hybrid corn to the market by observing the patented product's success and this can spur them to try other hybridization processes. Thus, Wagner writes:

> …because even perfectly controlled works nonetheless transfer significant information into the public domain, it turns out that over the long term, additional control is likely to stimulate additional works—and thus grow the public domain, even assuming no access to the protected work itself.[31]

On a more pragmatic note, Wagner observes that granting a right and actually enforcing it are two distinct things: "a great deal of intellectual property infringement occurs every day."[32] Thus, even well intentioned intellectual property right policies provide less restriction in reality than on paper.

Epstein and Kuhlik (2004) point to patent holders' self interest as another deterrent to the tragedy of the anti-commons.[33] Patent holders, at least non-vertically integrated ones, profit from licensing their patents, thus the authors argue that:

> Refusing to deal is a loss of opportunity. In addition, the patent is always a wasting asset; not only is it limited in time, but even during the period of its unquestioned validity its holder faces the possibility that new patents, old patents that have expired, and new techniques that come into the public domain will erode its dominance. Those who do not deal will not prosper…[34]

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[30] Id, p. 995.
[31] Id, p. 1000.
[32] Id, p. 1010.
[33] Epstein and Kuhlik, *supra* note 10, p. 55.
[34] Id.

B. Patent Thickets

In 2001, Shapiro pronounced the existence of a "patent thicket" in "several key industries".[35] The main extension in his paper is the application of the anti-commons theory to high technology industries involved in standard setting. In particular, Shapiro argues that

> [t]he need to navigate the patent thicket and hold-up is especially pronounced in industries such as telecommunications and computing in which formal standard-setting is a core part of bringing new technologies to market.[36]

To bolster this claim, Shapiro cites the dramatic increase in patenting in these two sectors:

> [T]he danger of paying royalties to multiple patent owners is hardly a theoretical curiosity in industries such as semiconductors, in which many thousands of patents are issued each year and manufacturers can potentially infringe on hundreds of patents with a single product.[37]

Nonetheless, Shapiro does not present any evidence on licensing difficulties or hold-up within the semiconductor or telecom industries.

One of the key distinctions for the anti-commons theory as applied to standard setting lies in the timing of licensing negotiations. For those technologies that are easy to invent around, "the patented technology contributes little if anything to the final product, and any 'reasonable' royalty would be modest at best."[38] But Shapiro and others argue that after the technology is included in a standard or after potential licensees have started manufacturing, the patent holder "can credibly seek far greater royalties, very likely backed up with the threat of shutting down the manufacturer…" Shapiro sees little relief for this ex post hold-up aspect of patent thickets short of reforming patent law.

For the "complements or royalty stacking problem" associated with the tragedy of the anti-commons, however, Shapiro is more optimistic. Here, he argues

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[35] Shapiro *supra* note 4. More recent papers have applied the patent thicket logic to the field of nanotechnology. See, for example, Ted Sabety, "Nanotechnology Innovation the Patent Thicket: Which IP Policies Promote Growth?" *Albany Law Journal of Science and Technology*, 2005.
[36] Shapiro *supra* note 4, at abstract.
[37] Id, p. 7.
[38] Id, p. 7.

that "the evolving and growing role of cross licensing and patent pools" offer a solution.[39] As noted earlier, formal standards generally involve a number of complementary patents, each covering a distinct component of the standard. Firms wishing to implement the standard must obtain licenses for all of the necessary components they do not already have rights to. Thus, the standard may increase its chances of success in the marketplace if firms agree to cross licensing. As an alternative to a series of bilateral cross-licensing agreements, owners of patents deemed essential to a standard may opt to form a patent pool in order to bundle at least some subset of the essential IP rights into a single package for easier licensing.[40] Voluntary mechanisms of this sort enable manufacturers to obtain the necessary complementary rights for implementing a standard.

Cross licensing and patent pools do, however, involve costs. With cross licensing, bilateral negotiations can be time consuming and difficult. In particular, it is often quite hard to estimate the value of patents, but some sort of value calculation may be necessary in order to offset the two parties' portfolios and arrive at a net price. Moreover, both cross licensing and patent pools can be used for anticompetitive objectives, so these arrangements are regularly overseen by competition authorities.[41] Nevertheless, despite the costs, cross-licensing and patent pools may alleviate the problems created by increased patenting and fragmentation of patent holding.

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[39] Id, p. 3. Both cross licensing and patent pools have been much discussed in the literature as means of cutting through patent thickets. See, for instance, Robert Merges, "Institutions for Intellectual Property Transactions: The Case of Patent Pools," Unpublished working paper, University of California at Berkeley, 1999.

[40] Participation in a patent pool is entirely voluntary and rarely, if ever, includes all eligible firms. See Layne-Farrar and Lerner *supra* note 28

[41] While cross licensing is less scrutinized than pools are, there have been some antitrust problems. Shapiro describes Intel's cross licensing practices, which the Federal Trade Commission attacked in 1998, in discussing the potential for competitive misuse. When Intergraph threatened to file an infringement suit against Intel, Intel responded by revoking all of its IP from Intergraph, even though that IP was covered under a non-disputed cross license. See Shapiro *supra* note 4, at p. 13. Patent pools, on the other hand, can be vehicles for cartel when non-essential or substitute patents are combined into a single take-it-or-leave-it bundle. See Lerner, Josh and Tirole, Jean, "Efficient Patent Pools" (August 5, 2002). Available at SSRN: http://ssrn.com/abstract=322000; Richard J. Gilbert, "Antitrust for Patent Pools: A Century of Policy Evolution," Working Paper, October 3, 2002; Roger B. Andewelt, "Analysis of Patent Pools Under the Antitrust Laws," *Antitrust Law Journa*l, vol. 53, 1984.

C. Patent Holdouts and Patent Hold-up

A related, but distinct, strand of the literature focuses on non-cooperation. Under so-called patent holdout and hold-up, a firm with relevant IP emerges after a standard is set and demands high royalty payments. Thus, the focus in this strand of the literature is not on too many rights spread across a great many rights holders, but rather on the behaviour of one rights holder. In some instances, that firm may participate in the standard setting process, at least to some extent, but either does not declare its relevant patents to the standardization body or declares them but then prices those patents unreasonably high during *ex post* negotiations.[42]

The ambush strategy of participating in a standard but not disclosing the relevant intellectual property rights has become considerably more risky in recent years, since a number of these cases have been prosecuted as unfair conduct or breach of contract.[43] But, of course, some holdouts never directly join in standard setting efforts. They instead watch the process from the sidelines and reveal their patents after a standard has been set.

Shapiro (2006) argues that hold-up is a regular occurrence "in the information technology sector where a single product can incorporate many patented features".[44] He develops a model in which patent holders use the threat of seeking an injunction for patent infringement to push firms into paying more for a license than the underlying technology deserves. The intuition is that a manufacturer facing plant shutdown or a costly product redesign will be willing to pay considerably more than a patent is "worth" to avoid those costs.[45] As Lichtman (2006) describes it, the patent holder who surfaces after a standard has gained wide acceptance "can demand

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[42] See, for example, the discussion of Wang's refusal to license its Single In-Line Memory Modules (SIMMs), after lobbying JEDEC to adopt the technology as a standard, in Janice M. Mueller, "Patent System Reform: Patent Misuse Through the Capture of Industry Standards," *Berkeley Technology Law Journal*, Spring 2002, pp. 659 – 660. This article also discusses *In re Dell*, another holdout case. Id, pp. 666 – 668.

[43] See, for instance, *Rambus, Inc. v. Infineon Techs*., 155 F.Supp. 2nd 668 (E.D.VA 2001), *Rambus, Inc. v. Infineon Techs AG*, 318 F.3d 1081, 1096 (Fed. Cir. 2003), *In re Dell Computer. Corp.*, 121 F.T.C. 616 (1996).

[44] Carl Shapiro, "Injunctions, Hold-Up, and Patent Royalties," Working Paper, Draft 17 April 2006, http://faculty.berkeley.edu/shapiro/royalties. Merges & Nelson (1990) also points out the importance of patent strength in the holder's ability to hold-up a potential licensee: "[t]he chances of being successful depend on the relative contributions of the original patented invention…" Merges & Nelson *supra* note 18, at p. 865.

[45] Lemley (2006) echoes many of the same arguments, without any models: "Our goal should be to create a world in which patent owners can get paid for the technology they contribute, but in which what they get paid bears some reasonable resemblance to what they actually contributed." Lemley, *supra* note 9, at p. 4.

not only a royalty that reflects [the] intrinsic value but also a royalty that reflects the value of the infringing firm's standard-specific investments."[46]

As a solution to the hold-up problem, Shapiro (2006) calls for policy changes to improve patent quality, reducing the odds that a weak patent is granted by the patent office. He also suggests that

> [r]outinely granting stays to permanent injunctions to provide infringing firms the time to design non-infringing products causes negotiated royalty rates to fall…[47]

Lemley (2006) shares the view that injunctions are a key leverage tool. He posits that a commitment to license made to a standard setting organization "takes off the table the threat of injunctive action", leaving the parties to negotiate a reasonable royalty without the overhang of an infringement lawsuit.[48] As a result, according to Lemley firms participating in a standard and disclosing their intellectual property forgo the option of an injunction, which facilitates licensing.

In addition to licensing commitments, Lemley (2006) suggests ex ante licensing, where IP holders within a standard setting organization (SSO) would commit to a particular royalty prior to the definition of a standard. He admits that this would be difficult to accomplish in practice, but considers that SSOs might at least set up internal arbitration or discussion procedures for licensing disputes, so the parties could avoid the courts. Lemley does not advocate SSOs setting cumulative royalty rate caps, however, since "antitrust is right to worry that SSOs who see their members as mostly buyers rather than sellers of IP rights will set a total royalty rate that is artificially low."[49]

Lichtman (2006) offers a different view of the hold-up problem. He argues that at some point, a fragmentation of IP rights—so denigrated in the anti-commons theory—can actually be a good thing:

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[46] Doug Lichtman, "Patent Holdouts in the Standard-Setting Process," Academic Advisory Council Bulletin 1.3, May 2006.
[47] Shapiro, *supra* note 44, Theorem #4, p. 21.
[48] Lemley, *supra* note 9, at p. 6.
[49] Lemley, *supra* note 9, p. 7.

> The large number of overlapping patents that makes it difficult for firms to license necessary rights at the same time dampens the costs associated with each specific failure to license. …some resources will come into efficient use precisely because there are so many patent holders who each can plausibly veto another firm's use.[50]

In other words, when a relatively large number of firms follow a patent holdout strategy, actual hold-up is far less attractive:

> More patents means less money per patent holder. Less money, in turn, means less of an incentive for a firm to strategically delay in the hopes of being a patent holdout, and less of an incentive for an accidental patent holdout to actually bring suit.[51]

D. Royalty Stacking

And so we finally come to royalty stacking. In one regard this theory is the anti-commons problem writ less extreme. Rather than grinding all innovation to a halt, the many intellectual property rights distributed across numerous rights holders lead to an extremely costly and inefficient outcome just shy of an anti-commons tragedy. In another regard, the royalty stacking theory is the patent hold-up problem writ more extreme. Licensors are asking for royalty rates that, in the aggregate at least, are uneconomic for those firms attempting to implement the standard.

There is no bright line between any of these theories. One firm with a royalty rate of 60% would probably qualify as patent hold-up while 60 firms each asking for 2% would qualify as royalty stacking and could lead to a tragedy of the anti-commons if licensing negotiations were ultimately unsuccessful. The area in between these two extremes is gray. Would four firms each asking for 10% fall under hold-up or royalty stacking, or even be considered reasonable under certain circumstances? The literature has tended to view rights dispersion in single digits as concentrated, primarily because transaction costs typically do no prohibit bilateral negotiations when a limited number of firms are involved. For instance, a survey respondent discussing licensing issues in the biomedicine field noted that having to negotiate

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[50] Licthman, *supra* note 46, p. 13.
[51] Id., p. 10.

with "3 to 6" rights holders was "manageable".[52] In the end, then, the distinction between "fragmented" and "concentrated" is an empirical one dependent on industry and firm details.

Emphasizing the correlation between the various licensing theories, Lemley and Shapiro (2006) extend the discussion of patent hold-up and injunctions from Shapiro (2006) to royalty stacking. They note that

> [a]s a matter of simple arithmetic, royalty stacking magnifies the problems associated with injunctive threats and hold-up, and greatly so if many patents read on the same product.[53]

Lemley and Shapiro argue that a manufacturer's margin is a limiting factor in royalty negotiations, but that amount typically leaves considerable room for patent holders to overcharge compared to the value of their technological contribution.

E. Empirical Literature

As should be obvious by now, all of the above theories are just that—theories. The empirical literature testing the validity of these theoretical claims in the real world is considerably smaller than the theoretical one. More importantly, the empirical evidence developed so far is largely inconclusive. The royalty stacking theory is still in need of verification.

1. Evidence from the Semiconductor Industry

The semiconductor industry plays a prominent role in the anti-commons/royalty stacking literature. Here, the evidence of licensing problems is mixed. Hall and Ziedonis (2001) examine the patenting behavior of publicly traded U.S. firms in the industry using both patent data and surveys.[54] In particular, they test whether the pro-patent policy changes in the 1980s (including the creation of the centralized appellate court, the U.S. Court of Appeals for the Federal Circuit) changed patenting behavior among semiconductor firms, and if so, whether any harmful effects are evident as a result. Indeed, the authors do find that large-scale

[52] Walsh et al. *supra* note 16, p. 10.
[53] Lemley and Shapiro, *supra* note 4, p. 2.
[54] Hall and Ziedonis, *supra* note 15 .

chip manufacturing firms invested "far more aggressively in patents" after the policy changes, so that it appears these firms may be "engaged in patent portfolio races."[55]

On the other hand, Hall and Ziedonis also find that considerably more firms entered the industry after the policy changes, particularly specialized design shops that outsource all semiconductor manufacturing. Their interviews "suggest that stronger patent rights are especially critical to these [design] firms in attracting venture capital funds and securing proprietary rights in niche products."[56] Moreover, their interviews highlighted an increased role for patenting in firms' operations—patent attorneys were more involved in strategic alliances, licensing, and litigation decisions. Thus, they do not find evidence of licensing difficulties.

In a later paper, Ziedonis (2004) reassessed patent licensing in the semiconductor industry, this time investigating the degree to which the rights were spread among multiple owners (rights fragmentation). Based on patent thicket and anti-commons theory, along with insights from transaction cost theory, Ziedonis predicted that firms would patent more aggressively than expected when the rights to the technology are highly fragmented:

> a firm's bargaining challenge is affected by the level of *dispersion* among rights holders—not just by the number of patents in a 'thicket' or the number of owners per se (as modeled by Shapiro, 2001).[57]

That is, when the rights are spread across more players, transaction costs are higher and firms will patent more as a defensive measure, to provide bargaining chips in ex post licensing negotiations.[58] This effect should be even more pronounced for capital intensive firms, since manufacturing assets are difficult to redeploy. When rights are concentrated, however, bargaining ex ante is feasible and strategic patenting will be less important.

As a measure of concentration, Ziedonis constructs a fragmentation index based on patent prior art citations for a group of 72 firms over 21 years. If a firm's

[55] Id., p. 104.
[56] Id.
[57] Ziedonis, *supra* note 15, p. 807.
[58] Note that this sort of defensive patenting is typically aimed at cross-licensing, and thus does not imply anything in relation to royalty stacking.

patents cite a wide group of rivals' technologies, the rights are considered fragmented. She uses this measure on the premise that citations reveal "some of the technological antecedents of a patent", but also because the owners of cited patents are "reasonable proxies for potential licensors".[59] She finds that, as predicted, capital-intensive firms patent five times as aggressively in response to average levels of fragmentation compared to firms with average capital intensity, even after she controls for R&D spending and firm size. However, these firms only patent intensively when confronted with fragmented rights. Ziedonis concludes that her results "suggest the 'patent portfolio races' identified by Hall and Ziedonis (2001) are not driven by capital-intensive firms per se, but by the subset of firms that build upon fragmentary pools of external technologies."[60] Even so, her findings suggest a private solution to anti-commons: increased patenting for cross licensing negotiations. Indeed, Shapiro observes that

> the impressive rate of innovation in the semiconductor industry in the presence of a web of such cross-licenses offers direct empirical support for the view that these cross-licenses promote rather than stifle innovation.[61]

These observations suggest that market-driven mechanisms can effectively deal with potential royalty stacking problems and thus help to eschew any anti-commons tragedy.

2. Evidence from the Software Industry

Noel and Schankerman (2006) analyze patenting in the software industry, observing that "[l]ike semiconductors, software is a classic example of a complex technology in which cumulative innovation plays a central role."[62] They consider two aspects of patent thicket theory: patent portfolio size, which captures bargaining power, and fragmentation of patent rights, which captures the transaction costs of enforcing patent rights.

[59] Id, p. 810.
[60] Id, p. 805.
[61] Shapiro, *supra* note 4, p. 13.
[62] Noel & Schankerman, *supra* note 14, p. 4.

Examining large, publicly traded companies, Noel and Schankerman find some evidence of what they term "strategic patenting", but no substantially negative consequences. In particular, they find strong positive R&D spillovers from patenting for other firms' market values within a close technology field.[63] They also find that relatively high patenting by a close technology rival reduces a firm's patenting, counter to the patent portfolio arms race theory. And the authors find a strong positive patent premium (i.e., patenting increases market value), which they interpret as an indication that patents are important as a means of appropriating innovation rents in software. However, Noel and Schankerman also find that higher levels of fragmentation in citation rights increases a firm's patenting and lowers its market value somewhat, after controlling for a number of factors through regression analysis.[64] This last finding is consistent with the negative portfolio building effects found in Ziedonis (2004) and with royalty stacking theory. This evidence is not conclusive, though, because rights fragmentation raises transaction costs by requiring negotiations with more parties, regardless of the royalty rate charged. Thus the limited negative effect on market value could be driven solely by negotiation costs, with no relation to royalty stacking.

3. Evidence from the Biomedical Industry

The biomedical industry is the most frequently named industry for the existence of patent thickets and royalty stacking. Some anecdotal evidence exists here, but again it is inconclusive. Tullis (2005) relies on arguments about where biotechnology research *should* be:

> …biotechnology held the promise for a new generation of revolutionary products and treatments in the 1980s. However, twenty years later, the promise of biotechnology potential remains only a

[63] Market value, as a direct reflection of profit margins, is a relevant variable for the question of royalty stacking and strategic patenting effects. Under the efficient market theory, a firm's stock price will reflect all available information about the firm and its ability to earn profits. As a result, market value reflects the discounted present value of a firm's expected cash flows. Anything expected to disrupt those cash flows, such as increased licensing payments, can be expected to affect market value. See Eugene F. Fama, "Efficient Capital Markets: A Review of Theory and Empirical Work," *Journal of Finance* (May 1970).

[64] They find that a 5% increase in concentration increases market value by less than 2%.

> promise… Arguably, this shortfall in biotechnology innovations is the result of a biotechnology anti-commons.[65]

That may be true—or it may not be. Determining how the world would have been "but for" some reality is always a daunting task, and any number of contributing factors may be responsible for the unfulfilled promise in biotechnology research. In particular, Adelman (2005) points to "the disparity that exists between the power of biotech methods to generate data, such as genome sequences, and to produce effective medical procedures and drugs" as the real culprit behind any unfulfilled promises.[66]

Looking at the "should be" question from the other side, Epstein and Kuhlik (2004) consider what we should see if the anti-commons theory were correct for biomedical research. They argue that we would expect a decline in the levels of research and development, the value of new patented materials, or the number of patents filed and granted. Yet there is little evidence that any of this has taken place.[67]

Kitch (2003) concurs, noting that with so many years of history, anti-commons proponents should surely be able to list specific examples by now. He writes:

> …it is notable that no one who expresses these concerns [over an anti-commons tragedy] points to particular patents or particular patent licensing policies that have caused problems. Patents on basic research techniques are licensed widely at license fees which the research community is prepared to pay. …The field, meanwhile, continues to advance and the level of activity is high.[68]

Kitch argues that in other industries historical examples of licensing difficulties are available—such as the Wright brothers' airplane patents at the time of World War I—so a real tragedy of the anti-commons should have some tangible

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[65] Terry K. Tullis, "Application of the Government License Defense to Federally Funded Nanotechnology Research: The Case for a Limited Patent Compulsory Licensing Regime," *UCLA Law Review*, October 2005, p. 287.

[66] Adelman, *supra* note 10

[67] Epstein & Kuhlik *supra* note 10, p. 55.

[68] Edmund Kitch, "Comment on the Tragedy of the Anticommons in Biomedical Research," in Perspectives on Properties of the Human Genome Project Advances, F. Scott Kieff ed., *Advances in Genetics*, Volume 50, 2003.

evidence. Merges and Nelson (1990) discuss other prominent historical examples, such as in the radio industry in the mid to late 1910s where patent infringement fights eventually led to the formation of a new company, RCA, to consolidate patent rights.[69]

In a somewhat more rigorous approach, Walsh, Arora, and Cohen (2003) conducted interviews with biomedical researchers, academics, government officials, and representatives at non-profit organizations.[70] While they report that "research tool patents can impose a range of social costs, and there is some restriction of access", they also find "little evidence of routine breakdowns in negotiations over rights."[71] The disconnect between academic theory and industry perception, according to Walsh et al., is that while a great many patents might be filed on the same subject, when more thorough patent clearance reviews for licensing are conducted firms often find that many, if not most, of the patents from the initial search can be eliminated, leaving a relatively small list for license negotiations. More generally, the authors find a number of

> 'working solutions' that allow research to proceed, … taking licenses, inventing around patents, going off shore, infringement (sometimes under an informal and typically self-proclaimed research exemption), the development and use of public databases and research tools, and court challenges."[72]

The authors admit, though, that while these options are privately rational, they may "constitute a social waste."[73] Interview evidence is clearly more substantial than "what if" speculation, but it is also not the hardest of evidence. Interviews about royalty stacking may not reveal actual behavior. In addition, how the questions are constructed and asked can have a significant impact on the answers given.[74] More

[69]Merges and Nelson,. *supra* note 18.
[70] Walsh et al. *supra* note 16.
[71] Id, p. 289.
[72] Id, p. 331.
[73] Id, p. 332.
[74] This is a standard complaint against survey evidence. Since Walsh et al. did not provide any details on their questionnaire and interview technique, Paul David (2003) has questioned their findings. See Paul David, "The Economic Logic of 'Open Science' and the Balance between Private Property Rights and the Public Domain in Scientific Data and Information: A Primer", SIEPR Discussion Paper No. 02-30, March 2003. Available at http://siepr.stanford.edu/Papers/pdf/02-30.pdf.

importantly, 70 or so interviews can be viewed as more anecdotal than conclusive evidence.

4. Two Controversial Case Studies

Lemley and Shapiro (2006) present two case studies as empirical evidence of a royalty stacking problem. They begin with 3G cellular technology, which involves several standards and a large number of patents disclosed by their owners as potentially "essential" for each one. For instance, for the European version of 3G, WCDMA, nearly 7,000 essential patents were declared to the European Telecommunications Standards Institute (ETSI) as of early 2004. This number is inflated, though, since it includes patents from all jurisdictions (U.S., Europe, Asia), many of which are counterparts filed for global coverage of the same rights. Nonetheless, even if we were to limit the patents to just those issued by the U.S. patent office, we would still have a sizeable number. And those patents are held by a fairly large number of firms—forty-one firms in all are represented, although roughly 75% of the patents are held by just four firms. At least on the surface, then, WCDMA may be a candidate for royalty stacking because innovation is cumulative and patenting is prolific. That said, this standard fails to meet the third criterion, that IPRs are fragmented, as we demonstrate below.

Lemley and Shapiro argue that a royalty stacking problem actually exists on the basis of one statistic: "ETSI's call not just for patents but for royalty rates at which the patentees would be willing to license those patents covering the standard that would be included in cell phones produced aggregate royalty rates of 130% of the total price of each phone!" We have been unable to identify the source for this dramatic figure.[75] Regardless of any preliminary "call" for royalty rates, in reality WCDMA technology is being licensed and has achieved remarkable penetration today, which belies any extreme cumulative royalty predictions made some time ago.[76]

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[75] The source that Lemley and Shapiro cite does not contain any reference to the 130%. According to Professor Lemley, the 130% stems from research a graduate student conducted. He has graciously offered to provide us with the source paper when he is able to locate it.

[76] "Takin' It To The Streets: An Update on WCDMA Market Developments Around the World," *Signals Research Group*, April 2006, p. 3.

In their Wi-Fi case study, Lemley and Shapiro (2006) again assume that the mere presence of a large number of rights holders necessarily implies a royalty stacking problem. They also note that one patent lawsuit related to the standard ended with a 6% royalty rate award. Certainly if every patent holder charged 6%, there could be a royalty stacking problem. But we cannot assume that. First, technological contributions vary substantially across patents,[77] so knowing that one patent was awarded 6% by the courts tells us nothing about the remaining IP. This one patent might have been the most pivotal for the standard whereas the other IP might be of lesser value. Second, court awarded royalty rates often include an element of punishment to ensure that future infringement is deterred. Thus, this one rate may be an outlier since it was the outcome of a lawsuit. Furthermore, Lemley and Shapiro note that several of the Wi-Fi standard participants had already formed a patent pool, meaning a substantial portion of the standard's IP is available in a single-price bundle.[78]

Taking all of the empirical evidence together, we have little more than a collection of suggestive stories. Arguably, one of the most rigorous investigations is by Noel and Schankerman for the software industry, and even their findings are inconclusive as regards royalty stacking. Unfortunately, the ideal data for analyzing royalty stacking predictions—licensing contracts and negotiated royalty rates before and after the policy changes that increased patenting in high technology fields—is simply not publicly available. The dearth of data is the primary reason for the lack of persuasive evidence in any industry to settle the intriguing, but as yet unsubstantiated royalty stacking theory.

[77] F.M. Scherer, S. Herzstein, Jr., A. Dreyfoos, W. Whitney, O. Bachmann, C. Pesek, C. Scott, T. Kelly, and J. Galvin, Pat*ents and the Corporation: A Report on Industrial Technology Under Changing Public Policy*. Boston, MA: Harvard University, Graduate School of Business Administration 2nd ed, 1959; Ariel Pakes, "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks." *Econometrica* 1986; Frederick M. Scherer and Dietmar Harhoff, "Technology Policy for a World of Skew-Distributed Outcomes," *Research Policy* 2000.

[78] See Layne-Farrar and Lerner *supra* note 27 for more on the Wi-Fi patent pool.

III. TESTING FOR ROYALTY STACKING IN THE 3G CELLULAR TECHNOLOGY INDUSTRY

Is there a royalty stacking problem in 3G mobile telephony, as claimed by Lemley and Shapiro? To investigate this issue, we constructed an empirical model of the 3G telecom industry based on the model developed by Noel and Schankerman (2006) for the software industry. This model allows us to test the impact on the market value of 3G telecom companies of changes in the degree of IP concentration.

As noted in Section II above, Noel and Schankerman found that the market value of the software companies in their sample was lower when the patent rights needed to develop and commercialize the technologies were more fragmented. A negative relationship between market value and the fragmentation of IP rights does not constitute conclusive evidence of royalty stacking, however. The negative relationship could be driven by the transaction costs inherent in multiple license negotiations, by royalty stacking resulting from those licenses, or by some combination of the two effects. In contrast, a finding that increased patent rights fragmentation did *not* affect market value would clearly indicate the absence of royalty stacking because if royalty stacking were a genuine problem, it would certainly be expected to lower profits and market value.[79] Thus, the test developed by Noel and Schankerman is only partially informative for our purposes: it can identify the absence of a royalty stacking problem, but it cannot conclusively prove its presence.

A. Cellular Telecommunications Industry Data

The first step in assessing royalty stacking within the cellular telecom industry is defining the universe of firms to analyze. We began with the firms participating in the development of the 3G standard under ETSI.[80] This list of 60 companies covers firms contributing patents to the 3G standard, and thus includes

[79] Market value is relevant here because higher royalty payments mean lower cash flows. Market value is equal to the discounted cash flow a firm generates. Therefore, market value will fall in the presence of royalty stacking.
[80] ETSI is acting as the repository organization for intellectual property declared essential for the WCDMA 3G standardization efforts. A number of other organizations are involved, including the 3G Partnership Project. At ETSI, we collected all IP declared to projects that are related to 3G including 3GPP, 3GPP/AMR-WB, 3GPP/AMR-WB+, GPP/EMS, AMR, GSM/AMR-NB, UMTS, UMTS/CDMA.

both R&D oriented firms and firms that conduct R&D and manufacture products for the downstream market, such as cell phone handsets. To this list we added firms from two SIC codes: 3663 (Radio and Television Broadcasting and Communications Equipment), which identifies cellular equipment manufacturers, and 4812 (Radiophone and Communications), which identifies cellular network operators. After this step, we had a total of 142 public companies, of which 98 also had relevant patent data.

Our dataset is comprised of one record per year for each of the public cellular telecom firms identified. We have company financial and operational data from Compustat for each firm for the period 1980 – 2005, although not every firm has data in every year.[81] The company variables from Compustat include sales, capital assets, and number of employees, among others. We also restrict the companies to those that have at least one patent relevant for the 3G standard.[82] We collect patent information for each firm from the U.S. Patent and Trademark Office (USPTO) website. The patent variables include patent file and grant dates, technology classes, and prior art listings. Our final panel dataset, once records with missing observations were deleted, contains 371 year-firm records representing 63 unique firms.[83]

B. Quantitative Analysis

We estimate an empirical model linking the so-called Tobin's q—i.e., the ratio of the market value of a company to its tangible assets[84]—to the (shadow) cost of physical capital and to the intellectual capital of the company, which is measured by the ratio of R&D spending to tangible assets and the ratio of patents to tangible assets. The cost of physical capital is, in principle, a function of the capital structure of the firm (e.g., the volume and terms structure of its liabilities), its net sales or net

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[81] Compustat data files are produced by Standard & Poor's Institutional Market Services, a division of McGraw-Hill, Inc. The principal contents of the data files are the items reported by companies in standard financial reports, such as quarterly and annual income statements, balance sheets, and cash flow statements.
[82] As noted earlier, in an ideal world we would have licensing contracts and prices for all firms in the industry. Since that data is not available, we rely on a licensing proxy developed in the literature, and explained below, that requires us to restrict our analysis to firms with at least one patent.
[83] Annex A contains a table listing these firms, along with an indicator of whether we consider them vertically integrated, operator, or upstream.
[84] James Tobin, A general equilibrium approach to monetary theory", *Journal of Money Credit and Banking*, Vol. 1 No. 1 pp 15-29, 1969.

revenues, and a few strategic patenting variables that capture the opportunity cost of investing the company's limited resources on tangible assets rather than on intellectual capital.

Thus our underlying model is:[85]

$$\ln\left(\frac{V}{A}\right)_{it} = \ln\kappa_{it} + \ln\left(1+\gamma\left(\frac{G}{A}\right)_{it} + \delta\left(\frac{PS}{A}\right)_{it}\right),$$

where V denotes market value, A is the stock of tangible assets, G is the stock of R&D, and PS is the patent stock, all for firm i at time t. The parameter κ_{it} represents the shadow price of physical capital, γ is the ratio of the shadow price of R&D capital to the shadow price of physical capital, and δ is the ratio of the shadow price of patent capital to the shadow price of physical capital. G/A and PS/A are the ratios of the R&D stock and the patent stock, respectively, to the stock of tangible assets. We further parameterize the shadow price of physical capital, κ_{it}, with strategic patenting and financial variables and with indicators to distinguish between operators, upstream and vertically integrated companies.[86]

Our model includes three strategic patenting or R&D variables: (i) the R&D spending of technologically close competitors, meant to capture spillover effects (ii) the patenting activity of those competitors (i.e., patent propensity), and (iii) the degree of concentration of the IP required by the company to develop its activities, meant to capture royalty stacking effects.

The R&D spillover and patent propensity effects are meant to capture the activities of "technologically close" rivals, thus we first derive technological proximity weights. Following Noel and Schankerman (2006), we measure the technological proximity between two firms as the uncentered correlation between their patent citations to the various patent classes (self-citations excluded), denoted by τ_{ij}^{NS}:

[85] Models of this sort have been used in this literature for more than two decades; for an early application see, for example, Z. Griliches, "Market Value, R&D, and Patents," *Economic Letters* 7 (1981).
[86] Vertically integrated firms are those with 10% or more revenue derived from the manufacture of handsets, modems, or other equipment. Chipset manufacturers are considered upstream, as are firms with no manufacturing of any kind.

$$\tau_{ij}^{NS} = \frac{W_i^{'}W_j}{\left(W_i^{'}W_i\right)^{\frac{1}{2}}\left(W_j^{'}W_j\right)^{\frac{1}{2}}}.$$

Here $W_i = \left\{w_{ik}\right\}_{k=1}^{K}$ is a vector denoting the shares of firm i's backward citations across patent classes, up to year t.[87]

To account for technology spillovers we created variables equal to the weighted sum of other firms' R&D Stock, weighted by the technological proximity measure:

$$SpilloverNS_{it} = \sum_{j \neq i} \tau_{ij}^{NS} G_{jt},$$

where G_{jt} is the R&D stock of firm j at time t.[88]

Patent propensity is defined by $Z_{jt} = \frac{PS_{jt}}{G_{jt}}$, i.e., the ratio of patent stock to R&D stock for firm j at time t. The patent propensity of a firm's rivals is thus the weighted average of the Z_{jt}, where weights are again given by the technological proximity measure.

To measure a possible patent thicket or royalty stacking effect, we follow the literature and examine the concentration of a firm's patents citations across its rivals. The prior art that a patent cites can be taken as an observable indicator of the rights holders that a firm might have to negotiate a license with in order to implement its invention.[89] Thus, the more fragmented those cites are (i.e., the more individual parties a patent lists as prior art), the higher the transaction costs for downstream and vertically integrated firms stemming from license negotiations *and* the more likely

[87] We investigated an alternative weight based on Jaffe (1986) which relies on a firm's patent activity across patent classes rather than its citation history: $\tau_{ij}^{J} = \frac{U_i^{'}U_j}{\left(U_i^{'}U_i\right)^{\frac{1}{2}}\left(U_j^{'}U_j\right)^{\frac{1}{2}}}$, where $U_i = \left\{u_{ik}\right\}_{k=1}^{K}$ is defined as the distribution of patents by firm i across patent classes k up to year t. See Adam Jaffe, "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value," *American Economic Review,* 76, 984-1001, 1986. The use of this alternative weight did not qualitatively change any of our results.

[88] We also created an analogous spillover measure based on the Jaffe weights.

[89] Ziedonis, *supra* note 15; Noel and Schankerman *supra* note 14; Iain M. Cockburn and Megan J. MacGarvie, "Entry, Exit and Patenting in the Software Industry," NBER Working Paper 12563, October 2006.

royalty stacking is to occur.[90] We calculate the share of firm *i*'s backward patent citations that cite firm *j* up to time *t*, and define this as s_{ijt}. The shares are sorted to create the citation concentration measure *Citecon4*, defined as the sum of citation shares among the top 4 firms.[91]

We expect the measure of concentration to have different effects on the different firm types. The royalty stacking predictions are aimed at firms implementing a standard. Thus, we expect higher rights concentration to have a positive impact on market value for vertically integrated firms. Upstream firms, however, are not so clear cut. As the recipients of higher royalty payments in a stacking situation, market value for these firms might fall with increased concentration. On the other hand, increased concentration might make follow-on research easier for upstream firms, which could lead to higher market value. Mobile network operators are also difficult to predict. The expected coefficient sign for C*itecon4* is therefore ambiguous for upstream firms and operators and positive for vertically integrated firms.

As Noel and Schankerman point out, the spillover variables raise some interpretation issues. Any shock that increases a firm's incentives to perform R&D and raises its market value is likely to have a similar effect on companies that are in the same technology space. In other words, a positive (negative) and significant coefficient on the spillover variables could indicate genuinely positive (negative) externalities taking place across firms or could, alternatively, reflect the impact of unobserved shocks that have a similar impact on similar firms. In order to control for these demand or technology shocks, we include a number of variables in the estimating equation in the spirit of Noel and Schankerman: we estimate the models

[90] This approach is not perfect. Again, the ideal data would be actual licensing contracts, identifying which parties contract with whom. Given that this data simply is not available, the next best alternative is a reasonable proxy. For upstream firms the proxy should be especially informative, as these firms will be dealing with the research that came before theirs in order to continue innovating. Also for vertically integrated firms the prior art proxy is reasonable. These firms are patenting in the space and manufacturing. The parties listed in the prior art cites should represent a good portion of those needed for cross licensing, although it may not capture everyone. For firms with no patents in the relevant space, however, the prior art proxy provides no information at all. It is for this reason that we exclude pure downstream firms from our analysis.

[91] $Citecon4_{it} = \sum_{j=1}^{4} s_{ijt}$ We also tested an 8 firm concentration measure and a tradition HHI measure using the sum of squared citation shares. All three sets of results were qualitatively the same.

with year fixed effects; we include two lags of the company net sales (*Net Sales*) on the right hand side; and we incorporate measures of technological opportunity. A measure of a firm's technological opportunity (*TechOpp*) is given by the weighted sum (over patent classes) of the patent stock of a company's technologically close competitors.[92]

We also included several financial variables.[93] The primary explanatory variables in the market value equation are *RDSTang* = *G/A*, the ratio of R&D stock to the stock of tangible assets, and *PSTang* = *PS/A*, the ratio of the patent stock to the stock of tangible assets.[94] Tangible assets are defined as the net stock of property, plant, and equipment. Patent and R&D stocks were created from patent and R&D flow variables by applying a 15 percent depreciation factor to the relevant flow variables.[95]

Finally, we extend the Noel-Schankerman framework to address different business types. In particular, we created an indicator variable *Vert* to measure the effect of whether a firm is vertically integrated, upstream, or a telecom operator. Upstream firms are defined as research-oriented firms (at least in relation to 3G). We include firms that manufacture chipsets, which downstream manufacturers then incorporate into handsets. Vertically integrated firms have R&D operations along with downstream operations (i.e., they manufacture handsets and other telecom equipment), while operators are carriers that have at least one relevant patent and provide mobile phone services to end customers.[96] Examples of upstream firms in

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[92] The idea behind including all these variables is to control for time-specific shocks that have a similar effect on companies that are close to one another in technology space. By definition, year fixed effects perform this function. Lags of the company's net sales attempt to control for any remaining demand shocks. (Noel and Schankerman also constructed an industry sales measure for each firm and estimated their models including this industry-wide control variable—the results they obtained were similar to the ones they reported with lags of the company's own sales.) The technological opportunity variables attempt to control for differences in patenting intensity across technological fields at a given point in time. According to Noel and Schankerman, "the idea is that firms cite patents similar in nature to its own, and if there is a large amount of patenting in areas it cites, it is an active technological field" (p. 16).

[93] All financial variables were normalized to year 2000 dollars using a GDP Deflator Index obtained from the US GPO website (www.gpoaccess.gov).

[94] Other financial variables, such as current liabilities and numbers of employees, were considered in the analysis but did not enter the final regression model.

[95] Following Hall, Jaffe and Trajtenberg (2000).

[96] In our dataset, 8 firms are upstream, 44 are vertically integrated, and 11 are operators.

our database include Qualcomm, Interdigital, and Intel. Nokia Corporation and Motorola, Inc. are among the vertically integrated companies.

Our estimating equation is,

$$\ln\left(\frac{V}{A}\right)_{it} = Z'_{it-1}\beta_1 + Y'_{it-1}\beta_2 + X'_{it-1}\beta_3 Y'_{it-1} + I'_{it}\beta_4 + \{I_{it}Y_{it-1}\}'\beta_5 + \varepsilon_{it}$$

Where Z represents the vector of the stock to asset ratio variables *RDSTang* and *PSTang*. *Y* represents the vector of strategic patenting variables (*Spillover, Patprop, Citecon4*), *X* represents a vector of control variables including *Net Sales* and *TechOpp* (technological opportunity), as well as two sets of indicator variables which represent fixed effects (one for firm and one for SIC industry group). *I* denotes a set of indicator variables representing the different firm types (operator, upstream, vertically integrated), and *{IY}* is the set of terms representing the interactions between firm type and the strategic patenting variables. ε is a random error term. All of the financial and patent-related variables were lagged one period.[97] Following Noel and Schankerman (2006), we also included two-year lags for *TechOpp* and *Net Sales*.[98]

C. Empirical Results[99]

Table 1 presents our estimation results. As the coefficient estimates indicate, we find that higher values of net sales, higher ratios of R&D expenditures to tangible assets, and higher ratios of patents to tangible assets all correspond to higher ratios of market value to tangible assets. In other words, firms that bring in more sales revenues have higher market values; firms that spend more on research and development have higher market values; and firms that have more patents have higher market values.

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[97] The rationale for lagging these variables is that if the variables are included in an estimating equation contemporaneously it is unclear what is causing what (or, in other words, it is unclear what is exogenous and what is endogenous).

[98] While Noel and Schankerman estimate an approximation of the *log(1+ γx)* function in the market value equation with a fifth-order polynomial, we did not follow this approach because of the extreme skewness of the stock variables. We tested several functional forms, including a logarithmic transform, and chose the third-order polynomials as the most appropriate.

[99] Annex A contains summary statistics for our dataset along with a discussion of our robustness tests.

Table 1: Regression Estimates, Dependent Variable = Market Value

Variable	Symbol	Coefficient	Std. Err.	P value
Flag for Upstream	up	-10.697	7.882	0.180
Flag for Operator	op	-1.205	16.422	0.942
R&D/Tangible Assets	rds_tang	0.106	0.072	0.143
(R&D/Tangible Assets)^2	rds_tang_2	-0.003	0.002	0.138
(R&D/Tangible Assets)^3	rds_tang_3	0.000	0.000	0.133
Patent Stock/Tangible Assets	ps_tang	0.682**	0.226	0.004
(Patent Stock/Tangible Assets)^2	ps_tang_2	-0.074**	0.025	0.005
(Patent Stock/Tangible Assets)^3	ps_tang_3	0.002**	0.001	0.008
Log Net Sales	ln_net_sal~c	0.516**	0.220	0.022
Lagged Log Net Sales	ln_netsale~1	-0.433*	0.219	0.053
Log Spillover	ln_spillov~w	-0.660	0.469	0.164
Log Patent Propensity	ln_patpropw	-0.414*	0.241	0.091
Citation Concentration	cc4m	1.124	1.328	0.401
Log Spillover * Upstream	ln_spil~w_up	0.887*	0.502	0.082
Log Patent Propensity * Upstream	ln_patp~w_up	0.335	0.667	0.617
Citation Concentration * Upstream	cc4m_up	2.758	3.510	0.435
Log Spillover * Operator	ln_spil~w_op	0.437	1.395	0.755
Log Patent Propensity * Operator	ln_patp~w_op	0.484	0.486	0.323
Citation Concentration * Operator	cc4m_op	-3.380	3.970	0.398
Log Technological Opp	ln_techopp	0.517	0.690	0.456
Lagged Log Technological Opp	ln_techopp~1	0.255	0.254	0.320
Flag for R&D	rz	1.038	1.430	0.470
Intercept	_cons	0.374	2.587	0.885
Year binary variables				<0.01
Industry binary variables				<0.01

*Notes: Estimated using OLS with robust (clustered) standard errors. The model also includes binary year variables and binary industry variables. Model estimated on 371 records. ** indicates statistically significant at the 5% or better level, * indicates significant at the 10% or better level.*

We also find that the impact of the R&D and patenting variables on market value differs across firm type, as the interaction variable coefficient estimates in Table 1 suggest. Table 2 presents coefficient estimates broken out by firm type.

Table 2: Strategic Patenting Coefficients for Upstream, Vertically Integrated, and Operator Firms

	Upstream		Vertically Integrated		Operator	
Variable	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Spillover	0.227	0.676	-0.660	0.469	-0.223	1.572
PatProp	-0.079	0.689	-0.414*	0.241	0.070	0.454
CiteCon4	3.882	3.347	1.124	1.328	-2.257	3.879

*Note: * denotes significance at the 10% level.*

The estimated effect of R&D spending by technologically close rivals on market value depends on company type. It is positive among upstream firms and negative among vertically integrated and operator companies, but it is never significant.

The estimated effect of the patent propensity of technological rivals depends on company type as well—it is negative among upstream and vertically integrated companies, and positive among operators, but it is only significant among vertically integrated companies. These results could be driven by a number of factors. First, firms faced with larger patent portfolios likely face higher transaction costs, since they could be at a relative disadvantage in negotiations.[100] The effect on negotiations need not be limited to patent licensing, but could cover all manner of negotiations given the litigation threat that a large patent portfolio can present to rivals. Alternatively, the negative coefficient might reflect the presence of a patent "arms' race", which would be expected to lower market value as the company's limited resources were inefficiently diverted toward "excess" patenting. Since we analyze market value only, and do not estimate the drivers of firms' patenting decisions, we cannot distinguish between these two effects.[101] Moreover, the general lack of statistical significance means that the effects could be zero.

[100] See Gideon Parchomovsky and R. Polk Wagner, "Patent Portfolios", *University of Pennsylvania Law Review*, November, 2005.
[101] Noel and Schankerman also find that increased patenting by technology rivals lowers a firm's market value. In addition, they find that patenting by rivals lowers a firm's R&D expenditures and its propensity to patent.

As predicted by the royalty stacking theory, the effect of rights concentration is positive for upstream and vertically integrated firms. (It is negative among operators.) However, none of the estimated coefficients are statistically significant. We estimated a wide variety of specifications to test how robust these results are. The estimated coefficients on the citation concentration variable are always positive for upstream and vertically integrated companies, are never statistically significant for vertically integrated firms, and are mostly not statistically significant for upstream firms either, except in a few of the dynamic panel data model specifications.

One key finding, and perhaps the reason for the absence of statistically significant effects, is the apparent lack of fragmentation of rights in our data. We find that among all public cellular telecom firms the concentration measure ranges from roughly 53% to 100%, with the average at 86%. A measure of 100% indicates that *all* of a patent's prior art listings are held by four firms or less. Among vertically integrated firms, average concentration is nearly 90%; i.e., 90% of the relevant patent rights are in the hands of just 4 patent holders. Since concentration at this level has nearly no statistically significant effect on firm market value, we conclude that four firms translate into concentration for this industry and fragmentation is low among public cellular telecom firms, especially among vertically integrated firms. Thus, we find that the predicted royalty stacking problem is not an issue in this industry.

IV. REVISITING THE ROYALTY STACKING THEORY

The absence of convincing evidence that royalty stacking is a genuine problem in high technology industries characterized by cumulative and sequential innovation suggests that something is missing from the theory. In this section, we analyze the theory more closely in order to identify any mitigating factors.

As explained in Section II.D, the royalty stacking theory states that when (a) innovation is cumulative and complementary, (b) there are many patents for a given product, and (c) patent ownership is widely dispersed, the following two propositions hold: (1) the royalty rates set by the holders of concomitant patents results in an excessively high cumulative royalty rate, and (2) the aggregate or cumulative royalty rate increases with the number of relevant patent holders, i.e., with the degree of IP fragmentation. Conditions (a) through (c) must hold for a royalty stacking problem to emerge. If any of those three necessary conditions are not met, royalty stacking would not be a real problem.

A. The Theory is Not Robust

These three necessary conditions, however, are not sufficient. That is, royalty stacking may not be a problem even if conditions (a) through (c) are satisfied. To see why, consider the linear demand model developed by Lemley and Shapiro (2006) to formally illustrate the possibility of royalty stacking. In this model, downstream output is decreasing in the cumulative royalty rate charged by N (upstream) patent holders. The model assumes, by construction, that patent holders cannot fully appropriate the rents generated by their inventions when they act non-cooperatively and negotiate simultaneously. Furthermore, Lemley and Shapiro restrict attention to symmetric equilibria where all patent holders charge the same royalty rate. Under those assumptions, Lemley and Shapiro find that downstream output is lower when the N patent holders act non-cooperatively than when they coordinate their behaviour in a single royalty rate negotiation, such as would emerge if all patent holders formed a patent pool. They also find that that the difference between the cooperative and non-cooperative solutions is greater in the presence of more upstream patent holders (larger N).

We analyze the robustness of these findings by relaxing the three assumptions made by Lemley and Shapiro. We rely on two extremely simple bargaining games satisfying all three of the abovementioned necessary conditions for royalty stacking.

1. The Baseline Model

Consider an industry consisting of an upstream market and a downstream market. In the *upstream market*, there are N patent holders, $N > 1$, each of which holds an essential patent,[102] indexed by i. Patent holders bargain independently and simultaneously with a single downstream firm. Each upstream firm sets a royalty rate r_i. R denotes the total cumulative royalty rate paid by the downstream manufacturer, $R = \sum r_i$. The incremental cost of licensing patents is equal to c for all patent holders and reflects the cost of the time and resources involved in negotiating a license agreement.

In the downstream market, there is a single player that requires all N upstream inputs; the patents are strict complements. We assume that the downstream profits are fixed and given by V—provided that all bargains are completed successfully and the total cumulative rate $R \leq V$—and 0 otherwise. That is, downstream profits are independent of the cumulative royalty rate. As a result, the demand for licenses is completely inelastic and, as we will show below, patent holders can fully appropriate the rents generated by their inventions, V. We assume that $V > N c$, to ensure that the bargaining equilibrium set is non-empty.

Licensing occurs in two stages. In the first stage, each licensor i sets its royalty rate r_i simultaneously and non-cooperatively. In the second stage, each licensor decides whether or not to license its technology given the royalty rates set by all patent holders. We solve this game by backward induction looking for subgame perfect equilibria (SPE).

Second stage. The solution to the second stage is trivial: each patent holder licenses its patent if and only if $r_i \geq c$.

First stage. Patent holder i chooses r_i^* to maximise its profits $r_i - c$, provided that $V - R \geq 0$. The optimal royalty rate r_i^* is increasing in V and decreasing in the cumulative royalty rate charged by the holders of all complementary patents. Furthermore, the equilibrium cumulative royalty rate R^* is independent of N and, hence, independent of the degree of IP fragmentation. In fact, we can show that:

> **Proposition 1.** *Any set of royalty rates $\{r_1^*, \ldots, r_N^*\}$ such that $R^* = V$ and $r_i^* \geq c$ constitutes a SPE of the baseline bargaining game.*

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[102] The results of this model extend immediately to a model where each patent holder owns and licenses a portfolio of essential patents.

Proof. First, in any SPE, we must have that $r_i^* \geq c$. Otherwise, patent holder i would refuse licensing in the second stage and the profits of all patent holders would be zero. Consequently, in equilibrium and for all i, $R^* - r_i^* \leq V - (N - 1)\, c$. Finally, given $r_{-i}^* = \{r_1^*, \dots r_{i-1}^*, r_{i+1}^*, \dots, r_N^*\}$, where $r_i^* \geq c$ and $R^* - r_{-i}^* \leq V - (N - 1)\, c$, the best response of patent holder i is to set r_i^* so that $R^* = V$. Q.E.D.

Thus, under the assumptions in the baseline model, which ensure that the downstream firm's demand for licenses is inelastic, the equilibrium cumulative royalty rate R^* when patent holders act non-cooperatively is independent of the number of licenses offered N and, hence, independent of the degree of IP fragmentation. There is no royalty stacking.

2. Extended Model

We now consider an extension of the baseline model where V is a *decreasing* function of R, $V(R)$. All other assumptions remain unchanged. This is a natural extension of the previous model. The profitability of the upstream patent holders is typically a function of the effort exerted by the downstream manufacturer in the production and commercialisation of the products where their innovations are incorporated. It may also be a function of the investments made by the downstream manufacturer, as they will determine both the quality of its products and the cost of producing them and, hence, the attractiveness of its offer to final consumers. The upstream patent owners will, therefore, want to encourage the downstream manufacturers to invest in its business and to exert maximum effort. However, those investments will not be undertaken unless the downstream manufacturer is properly remunerated. Consequently, downstream manufacturers should be expected to reduce their effort and/or investment levels in response to an increase in the cumulative royalty rate charged by the upstream patent holders. This would reduce downstream profits and the size of the cake available for the upstream players.

We assume that the royalty rate charged by patent holder i, r_i, is linear in $V(R)$: $r_i = \sigma_i\, V(R)$, where σ_i denotes the percentage royalty rate charged by patent holder i. As shown by Bhattacharyya and Lafontaine (1995),[103] linear revenue/profit sharing contractual arrangements between upstream and downstream companies, like

[103] See Sugato Bhattacharyya and Francine Lafontaine, "Double-sided moral hazard and the nature of share contracts", *RAND Journal of Economics*, 1995.

the ones specified here, are optimal when overall profits depend on the investments made and effort exerted at both levels of the vertical chain. Furthermore, the available evidence shows that linear sharing contracts as those assumed here are often used in practice.

In solving the model, we use backward induction again. For simplicity of exposition, we restrict attention to the set of $V(R)$ functions for which there is an interior equilibrium, i.e., an equilibrium where the downstream manufacturers appropriates part of the rents: $V(R)$ is such that (a) the second-order conditions of the maximisation problems analysed below are satisfied, and (b) $V(R) - R > 0$ in equilibrium.[104]

Second stage. The solution to the second stage is again trivial: each patent holder licenses its patent if and only if $r_i = \sigma_i V(R) \geq c$.

First stage. The profits of patent holder i, $\pi_i(\sigma_i)$, are equal to $\sigma_i V(R) - c$, provided that $V(R) - R \geq 0$. In consequence, σ_i^* solves the following first-order condition: $V(R) + \sigma_i \partial V(R)/\partial\sigma_i = 0$. In a symmetric SPE, $\sigma_i^* = \sigma^*$, so that the first-order condition becomes: $V(R) + \sigma^* \partial V(R)/\partial\sigma = 0$. The percentage royalty rate in the non-cooperative, symmetric equilibrium σ^* can be easily compared with the percentage royalty rate that would maximise the joint rents of the N upstream patent holders coordinating their pricing, σ^M, which solves the following first-order condition: $V(R) + N\sigma^M \partial V(R)/\partial\sigma = 0$. Comparing these two first-order conditions, we have that σ^M is lower than σ^*. That is, we find that, as predicted by the royalty stacking theory, the aggregate royalty rate when the N patent holders act non-cooperatively is greater than the cumulative royalty rate that a monopolist would charge. Furthermore, the difference between σ^* and σ^M is increasing in N, which indicates that the royalty stacking problem is increasing in the degree of fragmentation of the patent rights.

Even if we find royalty stacking when considering the symmetric equilibrium of the extended model, there are other equilibria which do not exhibit this problem.

[104] That is, (a) $V(R)$ is not too convex and (b) the elasticity of $V(R)$ at R^* is greater than R^*.

In fact, Proposition 2 shows that there are asymmetric SPE of the extended bargaining game which implement the joint profit maximising solution.

Proposition 2. *There are multiple asymmetric subgame perfect equilibria (SPE) of the two-stage extended bargaining game, provided that $c \leq c^*$. These equilibria can be characterised as follows: for all i, $\sigma_i^* = \beta^* - \mu^* (N-1)$ and $\sigma_j^* = \mu^*$ for all $j \neq i$, where (β^*, μ^*) are such that: (a) β^* maximises $\beta V(\beta V)$ and (b) $\mu^* V(\beta^* V) = c$. The cumulative percentage royalty rate in any of these equilibria equals the cumulative percentage royalty rate that maximises the joint profits of the N upstream patent holders: $N \sigma^M$.*

Proof. From (a) and (b), we have that $\mu^* = c / V(\beta^* V)$ and $\beta^* = N \sigma^M$. Hence, $\sigma_i^* = N \sigma^M - \mu^* (N - 1)$ and $\sigma_j^* = \mu^*$ for all $j \neq i$. It follows immediately that the cumulative percentage royalty rate in any of these candidate asymmetric equilibria equals $N \sigma^M$. To show that the candidate equilibria are indeed SPE of the two-stage extended bargaining game, consider first the incentives to deviate of player j for all $j \neq i$. Suppose player k set $\sigma_k < \mu^*$, its payoff would be less than c, which cannot be an equilibrium. Suppose instead it set $\sigma_k > \mu^*$. This would cause the cumulative percentage royalty rate to be greater than β^*. Hence, $V(R) < V(\beta^* V)$, which in turn implies that for all $j \neq i \neq k$, $\pi_j = \mu^* V(R) < \mu^* V(\beta^* V) = c$. But this cannot be part of a SPE because then all firms $j \neq i,k$ would not license their technologies and then π_k would be lower than if it had not increased its percentage royalty rate above μ^*. Consider now the incentives to deviate from the proposed equilibrium of player i. Patent holder i is extracting monopoly rents subject to the participation constraint of its competitors; it cannot be better off. If it lowered its percentage royalty rate, its payoff would be lower. If it raised it, the aggregate royalty rate R would be such that $V(R) < V(\beta^* V)$, and hence $\pi_j = \mu^* V(R) < \mu^* V(\beta^* V) = c$ for all $j \neq i$. Again, this cannot occur in an SPE because then all firms $j \neq i$ would not license their technologies and then π_i would be lower than if it had not increased its percentage royalty rate above $\beta^* - \mu^* (N-1)$. Finally, $c^* = [\beta^* - \mu^* (N-1)] V$. Q.E.D.

Aggregate welfare in any of these asymmetric equilibria is equal to aggregate welfare in the cooperative solution: upstream and downstream profits are identical in both solutions because the cumulative royalty rates are identical. Both solutions are thus equally efficient. Even though these asymmetric equilibria may appear rather artificial at first sight and, therefore, implausible in practice, note that they correspond to the unique SPE of a series of N games, where (a) patent holders bargain sequentially with the downstream manufacturer, (b) each game has a different patent holder as the first mover, and (c) the first patent holder to arrive into the bargaining table sets a percentage royalty rate equal to $\beta^* - \mu^* (N-1)$, and the remaining $N - 1$ patent holders have royalty rates equal to μ^*.

Under the extension model, the demand for licenses is elastic and patent holders cannot appropriate all the rents that are associated to their inventions. In this case, the symmetric equilibrium of the bargaining game when patent holders negotiate independently is characterised by royalty stacking. However, we find some asymmetric equilibria exhibiting no royalty stacking. Moreover, if we allow royalty rates to be negotiated sequentially, none of the equilibria exhibit royalty stacking.

These simple model specifications lead us to conclude that both the incomplete appropriability assumption and the symmetric equilibrium restriction are critical for the results obtained by Lemley and Shapiro. Relaxing these assumptions, the royalty stacking predictions weaken substantially. First, when patent holders can fully appropriate the rents generated by their inventions the degree of IP fragmentation may have *no* impact at all on the market value of the companies that must license the rights to develop their products lawfully. Second, even without full appropriability, if we drop the assumption of symmetric equilibria—i.e., allow patent holders to charge different royalty rates in equilibrium—or if we allow negotiations to be structured sequentially instead of simultaneously, the royalty stacking result is no longer guaranteed. In short, we find that the royalty stacking theory is not robust.

B. Interpreting the Empirical Results for the 3G Telecom Industry

Recall that we found no evidence of royalty stacking in the 3G telecom industry in Section III above. The discussion about the strength of the royalty stacking theory helps understand why. Without a doubt innovation in this industry is cumulative and "literally thousands of patents have been identified as essential to the proposed new standards for 3G cellular telephone systems".[105] Clearly, then, the necessary conditions (a) and (b) are satisfied. By contrast, however, condition (c) does not appear to hold: IP fragmentation is limited. On average 86% of all of a patent's prior art listings are held by four firms or less. Moreover, 64% of all patent

[105] Lemley and Shapiro *supra* note 4, at p.1.

citations across all components of the WCDMA 3G standard are in the hands of two patent holders: Qualcomm and Ericsson.[106]

But even aside from the apparent lack of IP rights fragmentation in the 3G mobile industry, the theoretical underpinnings of the model predicting royalty stacking do not match the reality of cellular standard setting. The royalty stacking model proposed in Lemley and Shapiro (2006) ignores that all key patents are regarded as strict complements by licensees and the elasticity of demand for licenses is bound to be low. Their assumption of equal patent contributions by all standard participants does not hold within the 3G standard.[107] Some components of the standard are crucial to its functioning—such as those defining the air interface that enables handsets to communicate with the network—whereas others are more peripheral—such as certain backward compatibility features. Furthermore, the evolution of the 3G mobile telephony business since the mid '90s is best represented as a sequential negotiation process, not a simultaneous one.[108] As each component of the standard evolves, the relevant parties negotiate the rights in light of all the components that came before and in anticipation of the components that might come after. The 3G standard has gone through 8 iterations over the last 6 years, with different elements of the standard shifting while others remained the same, and at each stage the relevant firms involved negotiated with one another to implement the new variant of the standard.[109] Yet when royalty rates are negotiated sequentially, royalty stacking either is not a problem or is a relatively minor one. For these reasons, we submit that the salient features of the cellular industry are better captured

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[106] Qualcomm patents have 47% of the citations, while Ericsson patents have 17%. Citation shares are based on US patents declared to ETSI 3G projects by May 2006. The following projects are included: 3GPP, 3GPP/EMS, 3GPP/AMR-WB, 3GPP/AMR-WB+, AMR, GSM/AMR-NB, UMTS, and UMTS/CDMA. The patents can be downloaded at: http://webapp.etsi.org/ipr/. We calculated forward citation measures using the USPTO's "USCITES04" dataset, which contains prior-art citations of all US patents granted between 1975 and 2004. The citation information for each individual US patent can also be accessed for free online at: http://www.uspto.gov/patft/index.html.

[107] *See* Annex B. See also, Anne Layne-Farrar, Jorge Padilla, and Richard Schmalensee, "Pricing Patents for Licensing in Standard Setting Organisations: Making Sense of FRAND Commitments, Working Paper, November 2006; David J. Goodman & Robert A. Myers, "3G Cellular Standards And Patents," Proceedings of IEEE WirelessCom 2005, June 13-16, 2005. Available at, http://eeweb.poly.edu/dgoodman/wirelesscom2005.pdf.

[108] Dave Mock, *The Qualcomm Equation: How a Fledgling Telecom Company Forged a New Path to Big Profits and Market Dominance*, Amacom Books: New York, 2005.

[109] *See* 3GPP Specifications - Releases (and phases and stages), at http://www.3gpp.org/specs/releases.htm.

by our two simple bargaining models—models that illustrate royalty stacking is not a problem, or at least not necessarily so.

V. CONCLUSIONS

In this Essay we have found that the gloomy predictions of those that claim that the growth of high tech industries is threatened by the proliferation of patenting are not justified. The royalty stacking theory is not robust and, what is most important, even in such industries where innovation is cumulative and products integrate many components each of which may be subject to one or more patents, there is no real evidence that royalty stacking is a problem in practice. In contrast to recent claims by Lemley and Shapiro (2006), we find no evidence of a significant royalty stacking problem in the 3G telecoms industry. And our review of the empirical literature indicates that the same holds true in the pharmaceutical, software and semiconductor industries.

The empirical and theoretical results of this Essay seriously question the underpinnings of recent proposals advocating various changes in antitrust enforcement and patent law, which are meant to address the purported tragedy of the anti-commons and the misfortunes caused by ever growing patent thickets. For example, Miller (2006) and Lemley and Shapiro (2006) have advocated limiting injunctive relief,[110] especially "when the product that would be enjoined contains multiple components, of which only one is the subject of the patent suit".[111] And Shapiro (2001) has defended a more lenient antitrust treatment of cooperative standard setting[112]—a position which seems to have inspired the Department of Justice's reaction to a proposal by the VMEbus International Trade Association (VITA) to implement a significant new patent policy requiring upfront disclosure of

[110] Joseph Scott Miller, "Standard Setting, Patents, and Access Lock-In: RAND Licensing and the Theory of the Firm," forthcoming in *Indiana Law Review*, vol. 40, 2006; Lemley and Shapiro *supra* note 4.
[111] Lemley and Shapiro *supra* note 4, at p.33.
[112] Others advocating a similar approach include, Mark A. Lemley, "Antitrust and the Internet Standardization Problem," *Connecticut Law Review*, vol. 28 (1996); Sean P. Gates, "Standards, Innovation, and Antitrust: Integrating Innovation Concerns Into the Analysis of Collaborative Standard Setting," *Emory Law Journal*, vol. 47. 583 (1998)

patents and patent licensing terms in connection with VMEbus standard-setting activities.[113]

While this Essay is not the place to judge whether those proposals may do more harm than good, which we believe would be the case, it should be clear from our analysis that such proposals are supposed to solve a problem which is more myth than reality. If we were to follow those policy recommendations, society would risk setting a course for Scylla in the absence of any evidence of danger from Charybdis.[114]

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[113] *See* VITA Patent Policy, at http://www.vita.com/disclosure/VITA%20Patent%20Policy%20section%2010%20draft.pdf ; Thomas O. Barnett,"Response to VMEbus International Trade Association (VITA)'s Request for Business Review Letter," Department of Justice, Antitrust Division. Available at: http://www.usdoj.gov/atr/public/busreview/219380.htm.

[114] For those of you who have forgotten your classical education, these are the two sea monsters from Homer's *Odyssey*. Scylla and Charybdis dwelled on opposite sides of a narrow strait so that sailors attempting to avoid Charybdis would fall prey to Scylla and vice versa. The monsters symbolize a state where one is between two dangers and moving away from one will cause you to be in danger of the other.

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ANNEX. EMPIRICAL ANALYSIS ON THE 3G TELECOM INDUSTRY

A. The Data

During the course of the analysis, we identified a handful of observations that were either response outliers or potentially influential cases. We conducted the analysis with these cases both included and excluded, and found that their removal had no impact on the final model conclusions.[115] As a result, the analysis reported includes all 371 cases, comprising 63 firms. The 63 firms are listed in Table 3 below.

Table 3: Companies included in Final Regression[116]

Firm	SIC	Type*	Firm	SIC	Type*
Airtouch Communications Inc	4812	O	Powerwave Technologies Inc	3663	VI
Cellnet Data Systems Inc	7389	O	Qualcomm Inc	3663	UP
Cisco Systems Inc	3576	VI	Relm Wireless Corp	3663	VI
Cobra Electronics Corp	3663	VI	Research In Motion Ltd	3663	VI
Comarco Inc	3663	VI	RF Monolithics Inc	3663	UP
Comtech Telecommun	3663	VI	S R Telecom Inc	3663	VI
DSP Group Inc	3663	UP	Sharp Corp - ADR	3663	VI
EFJ Inc	3663	VI	Siemens Ag - ADR	9997	VI
Electronic System Tech Inc	3663	VI	Spectralink Corp	3663	VI
EMS Technologies Inc	3663	VI	Stratex Networks Inc	3663	VI
Ericsson (L M) Tel -ADR	3663	VI	Sun Microsystems Inc	3571	VI
Globecomm Systems Inc	3663	VI	Technical Communications	3663	VI
Harmonic Inc	3663	VI	Tekelec	3663	VI
Intel Corp	3674	UP	Teledyne Technologies Inc	3663	VI
Interdigital Commun Corp	6794	UP	Telefonica Moviles Sa - ADR	4812	O
Itron Inc	3663	VI	Telephone & Data Systems	4812	O
L-3 Communications Hldgs Inc	3663	VI	Telesystem Intl Wireless	4812	O
Leap Wireless Intl Inc	4812	O	Telkonet Inc	3663	VI
Loral Space & Communications	3663	VI	Telular Corp	3663	VI
Lucent Technologies Inc	7373	VI	Terabeam Inc	3663	VI
Matsushita Electric - ADR	3600	VI	Texas Instruments Inc	3674	UP
Millicom Intl Cellular SA	4812	O	Thomson -Adr	3663	VI
Mitsubishi Ufj Finl Gp - ADR	6020	VI	Toshiba Corp	3570	VI
Mobile Telesystems Ojs - ADR	4812	O	Utstarcom Inc	3663	VI
Motorola Inc	3663	VI	Viasat Inc	3663	VI
NEC Corp - ADR	3663	VI	Viewcast.Com Inc	3663	VI
Nextel Partners Inc	4812	O	Vyyo Inc	3663	VI
Nokia Corp - ADR	3663	VI	Wave Wireless Corp	3663	VI
Nortel Networks Corp	3661	VI	Wavecom Sa - ADR	3663	VI
NTTDocomo Inc - ADR	4812	O	Wegener Corp	3663	VI
Omnipoint Corp	4812	O	WJ Communications Inc	3663	UP
Parkervision Inc	3663	UP			

*Notes: *Type: UP indicates an upstream firm, O indicates a mobile phone operator, VI indicates a vertically integrated firm. Vertically integrated firms have at least one relevant patent and manufacture handsets and other telecom equipment. Upstream firms include chip makers.*

Summary statistics for the important financial and patent-derived variables are given in Table 4 for the 371 observations that enter our final model.

[116] 79 companies including Panasonic, Cingular Wireless, Sprint, Merrimac, Gigabeam etc. were dropped from the combined ETSI and Compustat (SIC 3663 & 4812) dataset due to a lack of relevant financial and patent data.

Table 4: Descriptive statistics for Royalty Stacking Analysis

Description	Symbol	Mean	Median	Std. Dev.	Minimum	Maximum
Market value ($m)	Market_Val	19207	570	47221	1	458128
Net Sales ($m)	Net_Sales	7572	291	15096	0	93335
Patents Granted	Pat	183	2	378	0	1953
Property, Plant, Equipment, Net ($m)	PPE_Net	2016	60	4081	0	25941
R&D Flow ($m)	RD	882	29	1531	0	6287
R&D Stock ($m)	RDStock	3292	69	6506	0	30673
Patent Stock	PatStock	775	10	1653	0	8335
R&D Stock/ PPE_Net	RDS_Tang	4.7	2.3	9.5	0.0	111.9
Patent Stock/PPE_Net	PS_Tang	1.0	0.3	2.1	0.0	24.1
Market Value/PPE_Net	MarketVal_Tang	26.2	9.9	44.6	0.001	478.3
Technological Opportunity	TechOpp	959	841	546	31	2716
Spillover - NS	Spillovern	68146	68595	38554	1385	160468
Patent Propensity - NS	Patpropn	0.270	0.232	0.168	0.057	1.411
4-firm citation conc.	Citecon4	0.851	0.875	0.142	0.529	1.000

Note: Calculated on 371 observations from 1996-2005 that constitute the modelling data set

B. Robustness Tests

As reported in the main body of the paper, we estimated the econometric model using OLS (with robust standard errors) to determine the effect of the strategic patenting variables on market value. For the relevant patent-related variables, we tested both those based on the Noel and Schankerman backward-citation proximity weights, τ_{ij}^{NS}, and those based on the Jaffe self-patent proximity weights, τ_{ij}^{J}. We also tested the three versions of the patent-citation concentration index: the four-firm, eight-firm, and Herfindahl measures. The results do not change in any substantial form as compared to our baseline model.

In order to explore the robustness of the results to changes in specification, we estimated various alternative models (all of them with robust standard errors). Taking the base equation as a benchmark (Table 5a), we estimated the following modified models (one at a time). First, we removed the *TechOpp* variables, which are highly positively correlated with the *spillover* measures (Table 5b). Second, we added the lagged dependent variable as a right hand side variable in the base model to correct for potential serial correlation (Table 5c). (In other words, we estimated a so-called AR(1) model with additional explanatory variables.). Finally, we estimated various versions of a dynamic panel data model à la Blundell-Bond (Table 5d), which (a) introduces the lagged dependent variable on the right hand side of the estimating equation, (b) performs a first-difference transformation to control for unobservable company-specific heterogeneity, and (c) carries out the estimation in a GMM instrumental-variable framework to account for the lack of strict exogeneity in some of the right hand side variables (Table 5d).[117]

Table 5a. Strategic Patenting Coefficients (Base Model)

	Upstream		Vertically Integrated		Operator	
Variable	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Spillover	0.227	0.676	-0.660	0.469	-0.223	1.572
PatProp	-0.079	0.689	-0.414*	0.241	0.070	0.454
CiteCon4	3.882	3.347	1.124	1.328	-2.257	3.879

Notes: All other base-model variables included, as reported in the main body of the paper.

Table 5b. Base Model without Technological Opportunity Variables

	Upstream		Vertically Integrated		Operator	
Variable	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Spillover	0.711	0.517	-0.170	0.177	0.374	1.452
PatProp	-0.317	0.716	-0.598*	0.309	0.352	0.564
CiteCon4	3.181	3.444	1.146	1.443	6.459	7.058

*Notes: All other base-model variables included. * indicates statistically significant at the 10% or better level.*

[117] We estimated a wide variety of dynamic panel data models including different sets of variables in the so-called GMM set and the so-called IV set, and with different specifications as to how many lags to employ in the construction of the GMM instruments. The caveat in connection with the results we report is that the number of instruments was somewhat larger than the number of companies in the sample, and the rule of thumb is that the number of instruments should be no larger than the number of firms.

Table 5c. Base Model with Lagged Dependent Variable

	Upstream		Vertically Integrated		Operator	
Variable	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Spillover	0.098	0.298	-0.186	0.187	-0.520	0.553
PatProp	-0.291	0.379	0.128	0.179	0.657	0.469
CiteCon4	1.455	1.392	0.688	0.722	-4.643	7.236

*Notes: All other base-model variables included. * indicates statistically significant at the 10% or better level.*

Table 5d. Dynamic Panel Data Model

	Upstream		Vertically Integrated		Operator	
Variable	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**	**Estimate**	**Std. Err.**
Spillover	-0.297	0.448	-0.472**	0.219	-1.754	1.144
PatProp	-0.110	0.362	0.004	0.175	0.914**	0.465
CiteCon4	2.192	1.638	0.642	0.908	-2.739	6.175

*Notes: All other base-model variables included. * indicates statistically significant at the 10% or better level; ** indicates significant at the 5% or better level.*

The signs of the coefficients on the strategic patenting variables are reasonably stable across specifications for a given company type. The Spillover effect tends to be positive among upstream firms and is mostly negative among vertically integrated and operator companies. The Patent Propensity effect tends to be negative among upstream firms and positive among operators. (It is unstable among vertically integrated companies.) The Citation Concentration effect is consistently positive among upstream firms and vertically integrated companies, and mostly negative among operators. Very few effects are statistically significant, however. The Citation Concentration effect, for example, turned out to be significant only in certain dynamic-panel-data model specifications, and only for upstream companies. It was never significant among vertically integrated firms.