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Compete, Cooperate, or Both? Integrating the Demand Side into Patent Deployment Strategies for the Commercialization and Licensing of Technology

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Compete, Cooperate, or Both?

Integrating the Demand Side into Patent Deployment Strategies for the Commercialization and Licensing of Technology

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Abstract

Profiting from innovation typically involves a choice between commercializing a patented technology in the product market to exploit proprietary advantage (i.e., competition) or licensing the technology to an incumbent in the market for ideas (a form of cooperation). A firm may thus deploy a patented technology in ways that may differ in their aggressiveness toward, or accommodation of, competitors. We analyze the deployment of patented technology employing either competition or collaboration modes, or both together (i.e., coopetition), as well as switching among them across demand states or over time, or delaying these choices until more information is available. We thus view a patent as a bundle of real options that enables a firm manage not only the classic tension between commitment and flexibility but also the tension between competition and cooperation. We develop theory and propositions to predict which of these patent deployment modes will be chosen by an innovator facing an established firm as a function of the strength of the technology, market or bargaining power and other market conditions, particularly the level and volatility of market demand.

(179 words)

Key words: patent deployment strategies, technology commercialization, licensing, competition, cooperation, coopetition, real options, option games

INTRODUCTION

Over the years since the pioneering studies by Teece (1986) and Levin, Klevorick, Nelson, and Winter (1987) posed the fundamental question of how firms appropriate returns from their innovation efforts, the research literature has recognized that an innovator can choose to do so in ways that put it either in competition or in some form of cooperation with established rivals (Gans & Stern, 2003). For example, Netscape initially considered cooperatively licensing its technology to Microsoft in 1995 before choosing to compete directly via its own independent cross-platform browser. The deployment of a firm's patents is part of that core choice since patents can be deployed in various ways that differ in their implications for the firm's competitive or collaborative relationship with established firms – a phenomenon known as “strategic patenting” (Arundel & Patel, 2003). In addition to their conventional use based on exclusivity for protecting existing products or processes from direct imitation by competitors, an innovative firm may also deploy its patents strategically in two key ways:

1. *For competitive purposes* that benefit the firm at the expense of rivals, either offensively or defensively. *Offensive* aims include blocking competitors' ability to expand their future technology beyond what they have already patented (Ceccagnoli, 2009; Granstrand, 1999), sometimes called “bracketing,” or obstructing their rival's ability to conduct research and development (R&D) activities via patents on research tools or techniques (Heller & Eisenberg, 1998). *Defensive* tactics include protecting a firm's own technology from competition by substitute technologies (Hounshell & Smith, 1988) or preventing competitors from blocking the firm's own ability to expand its future technology beyond what it has already patented (Granstrand, 1999; Reitzig, 2004a), sometimes called “patent walls” or “patent fences,” or preventing competitors from obstructing the firm's ability to conduct R&D activities by patenting research tools or techniques before they do (Walsh, Arora, & Cohen, 2003).
2. *For cooperative purposes* that benefit a group of firms jointly. Such cooperation includes *beneficent* aims that allow rival firms to collectively **create** more value for their customers, such as cross-licensing their patented technologies to each other to achieve “design freedom” (Grindley & Teece, 1997), set common standards, or avoid a patent thicket or anti-commons, or unilateral licensing to obtain royalty revenue from other firms including rivals that can make better use of

the technology (Gans & Stern, 2003; Rivette & Kline, 2000b). Cooperative deployment may also include *collusive* type tactics that allow rival firms to collectively *capture* more value from their customers, such as attaining a stable cartel using licensing to disincentivize rivals from competing aggressively (Arora, 1997; Rubinfeld & Maness, 2005), or raising entry barriers to protect industry incumbents from external threats (Calabrese, Baum, & Silverman, 2000; Reitzig, 2004b).

Patent Deployment: Answered and Unanswered Questions

Why, and under what conditions, do innovators choose different patent deployment strategies that involve different types of competitive or cooperative relationships with established firms? Research on this strategic patenting phenomenon has focused predominantly on supply-side factors as drivers of the firm's choices of patent deployment strategy, such as the characteristics of the firm, the technologies, the rivals, the industry and the appropriability environment. For example, it is widely recognized that cooperation in the form of cross-licensing is more common in "complex product" industries that require combining multiple technologies whose patents are owned by different firms, which would otherwise leave these firms vulnerable to holdup problems (Cohen, Nelson, & Walsh, 2000a; Grindley & Teece, 1997; Hall & Ziedonis, 2001). By contrast, patent deployment in the form of a competitive defense is more common in "discrete product" industries where such technology combinations are not required (Reitzig, 2004a). Likewise, an offensive competitive stance to patent deployment is more common in industries that exhibit incremental innovation than in those involving more radical innovation (Ceccagnoli, 2009). Another key supply-side factor is the inherent degree of imitability or substitutability in the product market (lack of product differentiation), which encourages patent deployment that is more proprietary and aggressive (Polidoro & Toh, 2011) and less cooperative (Arora & Fosfuri, 2003; Hill, 1992). The appropriability environment also influences firms' patent deployment strategies (Gans, Hsu, & Stern, 2002; Gans & Stern, 2003; Teece, 1986). At the firm level, specialized complementary assets increase a firm's propensity to pursue a more proprietary or competitive approach to patent deployment (Arora & Ceccagnoli, 2006). Firms are more likely to license patents cooperatively when aiming to influence industry standards (Shapiro & Varian, 1999) but are less likely to license patents on core technologies that are central to their efforts to build and

sustain competitive advantage (Somaya, 2003). Mihm, Sting, and Wang (2015: 2666) predict firms' patent deployment strategies as a function of supply-side "internal contingencies (i.e., the firm's own R&D strategy) and environmental contingencies (i.e., the competitors' patenting and R&D strategies, industry clock speed and complexity)."

Hoffmann, Lavie, Reuer, and Shipilov (2018) highlight the interplay of competition and cooperation and balancing the associated tension between value creation and appropriation as a key research gap in strategic management. The current article aims to help fill this research gap in the context of patent deployment strategies by focusing on two key intertwined aspects of this interplay: incorporating what Brandenburger and Nalebuff (1996) call "coopetition" and considering switching over time. First, although much is already known about how firms choose between deploying patents in competitive versus cooperative ways, less is known about why a firm may do both simultaneously by aggressively commercializing the technology itself while also concurrently licensing it to competitors – i.e., the patent-deployment version of coopetition. Second, even less is known about why firms sometimes switch their patent deployment between the competition, cooperation, and coopetition modes under different demand conditions or over time. Both aspects are included in the analysis to provide related but complementary perspectives on this interplay as part of a comprehensive framework of analysis – as coopetition represents a third (hybrid) alternative to competition and cooperation that a firm may switch to over time under certain conditions. A number of unique insights emerge from addressing both aspects of this interplay (discussed in later Propositions 2.2 and 3). As we explain below, these two intertwined aspects of the main research gap concerning the interplay of competition and cooperation are partly due to the fact that prior studies have ignored product-market demand as a key factor to help explain patent deployment strategies. To clarify this connection, consider the limitations that have constrained extant research on both the independent- and dependent-variable sides of the equation.

Limitations of prior research on the independent-variable side. All of the aforementioned explanatory factors are focused solely on the supply side of the product market, with little or no consideration given to the role that product-market demand may play in explaining firms' patent

deployment strategies. Yet expert practitioners observe that “the phase of industry growth – for example, is it an emerging or a maturing business? – also shape[s] the IP strategy needs of each business unit” (Rivette & Kline, 2000b: 69). Mihm et al. (2015: 2670) also acknowledge this omission, as well as its significance, noting that the payoffs to various patent deployment strategies “are also affected by other factors... such as demand uncertainty.” Yet, we are aware of only two instances where research studies considered demand-side factors in explaining patent deployment strategies. On the theoretical side, a pair of formal models (Bar-Ilan & Strange, 1998; Weeds, 1999) consider the influence of demand on the timing of patent deployment (i.e., *when* the patent is deployed, but not how it is deployed). On the empirical side, Polidoro and Toh (2011) examine the level of product-market demand as a contingency factor influencing patent deployment strategy.

Using product-market demand to predict patent deployment strategy may not, by itself, generate significant new insights, as it is known that demand is an important determinant of market entry (e.g., see Cabral, 2000), and a patent deployment choice (commercializing the technology oneself versus licensing it out to rivals) is in some ways similar to an entry decision. However, more interesting than accounting for demand’s main direct effect is the question of how patent deployment choices are influenced by the *interaction* of both demand-side and supply-side factors. For example, given that a firm would behave less cooperatively for a patent that offers stronger technological advantages (Somaya, 2003), is this effect strengthened or weakened as demand conditions become more favorable? On the one hand, stronger demand raises the amount of value a firm can capture in the product market when keeping its competitive advantage proprietary by using its patents in an exclusionary way. But on the other hand, a stronger demand also raises the likelihood of a rival also producing profitably, which in turn increases the amount of licensing revenue a firm can capture in the market for technology by using its patent in a cooperative way. As a patent’s technological strength increases, under what conditions will the product-market benefit of stronger demand for the innovator, which requires more aggressive deployment, outweigh the rival entry and technology-market benefits, which favor cooperative deployment? Answering these questions requires addressing the interaction between factors on both the demand and supply sides.

An additional benefit of incorporating demand-side factors as independent variables to explain patent deployment strategies is that they tend to be more dynamic in nature and therefore offer a greater potential to explain why firms choose different patent deployment strategies under different demand conditions or switch their patent deployment strategies over time. Most of the supply-side factors that prior research has considered tend to be fairly static over time; if they change at all, they usually do so in slow, gradual, incremental ways. For example, a firm's stock of complementary assets (Arora & Ceccagnoli, 2006) cannot change quickly due to time-compression diseconomies (Dierickx & Cool, 1989). An industry's rate of innovation (Ceccagnoli, 2009), its degree of product substitutability or differentiability (Arora & Fosfuri, 2003; Hill, 1992; Polidoro & Toh, 2011), and the discrete versus complex nature of the technology (Cohen et al., 2000a; Grindley & Teece, 1997; Reitzig, 2004a) are fairly stable characteristics at the industry level. Although the appropriability environment (Gans et al., 2002; Gans & Stern, 2003; Teece, 1986) may sometimes shift due to occasional changes in patent law and related practices, it varies much more cross-sectionally among jurisdictions than it does longitudinally over time. We are aware of only a few cases where supply-side factors have been shown to affect patent deployment strategies in a dynamic way. First, when biology and genetics replaced chemistry as the main basis for drug discovery, the pharmaceutical industry shifted from a discrete product technology to a complex one, making licensing more common (Clark & Konrad, 2008). Second, voice-recognition patents were licensed more when the technology's strength became clearer to potential licensees (Marx, Gans, & Hsu, 2014). Yet, both of these instances represent unidirectional shifts toward greater cooperation via licensing over time; no supply-side factors have been shown to shift patent deployment strategies toward more competition over time.

Demand-side factors tend to be more dynamic than supply-side factors, for two reasons. First, industries typically experience a somewhat predictable product life cycle in which the level of demand for a product grows, matures, and eventually declines (Levitt, 1965; McGahan, 2004). Second, demand also may shift in stochastic or unpredictable ways due to fickle consumer preferences, economic shocks affecting customers' incomes, cultural fads and fashions, and many other reasons. Insofar as stochastic demand changes may affect the optimal use of a patent, a firm may benefit from retaining

flexibility to adjust patent deployment choices at a point in time as demand shifts or across time, e.g., from commercialization to licensing or vice versa. In this sense, patent deployment choices can be sensitive not only to the level of product-market demand but also to its volatility. Hence, strategic patent deployment has a real option value that has not previously been analyzed.¹

Limitations of prior research on the dependent-variable side. Most prior research treats the strategic patent deployment phenomenon as a discrete choice between incompatible alternatives, i.e., either competitive or cooperative. Yet firms often have more complicated relationships with each other that blend competitive and cooperative elements in what Brandenburger and Nalebuff (1996) call “coopetition.” With regard to patents, a firm may both exploit its patented technology for its own commercial use in the product market while also concurrently licensing the technology to direct competitors.² For example, Valeo, a French producer of vehicle parking sensor (ultrasonic) technology, licenses and supplies its sensor technology to a main European OEM auto producer while it concurrently sells parking sensors directly in the auto parts aftermarket and to independent operators. LG, which has developed the superior OLED TV technology, supplies OLED panels to many of its rivals in the consumer electronics market, such as Sony and Panasonic, while simultaneously competing with them in the global TV market. Tesla is currently facing the choice of keeping its electric car battery and driverless technologies for proprietary use or collaborating (e.g., with firms

¹ For example, Stanford professor John Cioffi, who invented the technology for ADSL telecommunications, recalls that “Bell Labs managers laughed at the idea of broadband over phone lines” and that an executive for a company that would later become a leading seller of ADSL services had told him, “I promise you we will never, ever deploy a single line of ADSL. You are wasting your time” (DeLacey, Herman, Kiron, & Lerner, 2006). The company Cioffi founded in 1991 to monetize his 25 patents, Amati Communications, secured approval from the American National Standards Institute (ANSI) in 1993 for its ADSL to become the U.S. standard, and started licensing its technology to a few telecom equipment manufacturers. Amati got off to a slow start, posting a loss of \$30 million on only \$13 million in sales in 1996, but Texas Instruments (TI) acquired Amati in 1997 for the stunning price of \$395 million in anticipation of rapid demand growth for ADSL (Rivette & Kline, 2000b: 145-148) and then began exploiting the ADSL patents far more aggressively. As TI had anticipated, consumer demand for ADSL equipment skyrocketed to over 100 million units per year by the early 2000s. Although the ANSI standard obligated TI to continue licensing the patents, TI did so under terms that were so egregiously onerous (i.e., only licensing ADSL patents in a package deal with a bundle of other TI patents that were unrelated to DSL) that the company was sued for antitrust violations in 2003, but eventually defeated that lawsuit in 2006. The intertemporal shift in this demand-driven situation is toward more competitive patent deployment over time, in contrast to prior supply-side examples (Clark & Konrad, 2008; Marx et al., 2014). This shift can best be understood in the context of a framework that considers the option value of switching patent deployment modes in response to demand shifts.

² For the purposes of this analysis, we treat licensing a technology as a cooperative deployment mode and self-commercialization as a competitive deployment mode. While this may hold in most cases, we nevertheless acknowledge that there may be occasional exceptions. For example, if a firm faces severe capacity constraints (e.g., a startup with limited capital), then self-commercialization may be much less competitive than it would otherwise seem. Conversely, licensing a technology (even on royalty-free terms) can be less “cooperative” if the license is given “with strings attached” – e.g., see the restrictive requirements for device manufacturers using Google’s Android operating system. For simplicity, we abstract from such situations as they are the exceptions from the rule.

like Panasonic on the car battery) and supplying rival automakers with these technologies. Moreover, coopetition and hybrid strategies may shift over time, as illustrated by the examples in Table 1. Such examples include Genentech's licensing of its patented synthetic insulin to Eli Lilly in the 1970's, Philips & Sony's collaboration on the CD player standard in 1979, and Dell's licensing its design technology to IBM and concurrently buying parts from it, while competing head on in the PC market. Similarly, Arora, Fosfuri, and Gambardella (2004: 172-173) observe:

DuPont and Dow Chemicals, two chemical firms with a long tradition of exploiting technology in-house, have started to license their technology very actively. Indeed, in 1994 DuPont created a division with the specific task of overseeing all technology transfer activities... Dow Chemicals has also long had a reputation for "never licensing breakthrough technology, and there was an emotional bias against licensing" (Ed Gambrell, V.P., Dow Chemicals). In 1995, it formed a licensing group with the purpose to "create more value" from its technology.

The above study provides numerous reasons why a firm may use a patented technology to compete in the same market while it simultaneously licenses the same technology to a competitor: to create cartel-like outcomes, commit to continue innovating, create demand, influence industry standards, deter entry, or to dissuade rivals from conducting related R&D projects (Arora et al., 2004: 175-178, 234).

[INSERT TABLE 1 ABOUT HERE]

This coopetition phenomenon can best be understood via a framework focused on how different patent deployment choices are interdependent: The pros and cons of licensing a patented technology depend critically upon whether the innovator also intends to commercialize the technology for its own use in the product market. Conversely, the pros and cons of commercializing a technology depend upon whether it will also be licensed out. These interrelations suggest that patent deployment choices should be made jointly, and have organizational implications for firms that delegate responsibility for different decisions to separate departments – e.g., where engineering, finance, and marketing managers make commercialization choices while lawyers drive licensing choices. Also, in the interplay between competition and cooperation, the benefit that a firm gains from deploying its patents competitively or cooperatively (or using both concurrently), and shifting between them over time, may depend upon the corresponding deployment choices of its rivals. In this regard, the phenomenon of strategic patent deployment involves strategic interactions among rival firms in a game-theoretic sense that also embed various patent use options.

Addressing Both Limitations Together

The issues on the dependent-variable side of the equation cannot easily be separated from those on the independent-variable side. After all, the level and volatility of market demand can influence the incentives of rival firms to compete, cooperate, do both concurrently, switch modes over time, as well as to enter or exit (Cabral, 2000). So it is necessary to address these two issues together, rather than separately. As a first step toward mitigating the limitations of extant patenting research on both the dependent- and independent-variable sides of the equation, we develop a theory that integrates dynamic demand-side factors and allows for cooptation in patent deployment choices as well as for shifting among competition and cooperation modes over time to better capture the interplay between competition and cooperation in the patent deployment context. Recognizing that both the strategic interaction among competitors and the flexibility to respond to demand volatility affect rival firms' patent deployment choices, we use a real-options game framework (Smit & Trigeorgis, 2004, 2017) as the basis of our theory. Our analysis further considers that both competition and cooperation can be implemented in multiple ways. Competition can take the form of a defensive or offensive patent deployment strategy. The first strategy involves clustering or building a "patent wall" of related patents surrounding one's own core patent (Arundel & Patel, 2003; Rivette & Kline, 2000a), while the second strategy involves "bracketing" or surrounding a rival's core patent with related patents of one's own (Cohen, Nelson, & Walsh, 2000b; Reitzig, 2004b; Rivette & Kline, 2000a). Likewise, cooperation may involve unilateral licensing of one's technology, as in the case of Genentech licensing its synthetic insulin patent to Eli Lilly, or bilateral cross-licensing of patents, as in the case of IBM and Dell in 1999, GSK and Nuevolution in 2009, or Google and Samsung in 2014 (see Table 1 for details).

Our analysis sheds light on the conditions under which patent deployment strategies may optimally switch between competition and cooperation or cooptation at a point in time depending on the level of market demand (i.e., across demand states) or across time periods depending on the volatility of market demand, given the strength of the innovator's patented technology, the bargaining power of the innovator versus the incumbent in licensing negotiations, and other factors. A main implication of our analysis is that the impact of patent deployment mode on rivalry in industry

equilibrium can have counterintuitive effects on the patent's value. For example, it is possible that a higher patent technological strength might actually backfire and reduce the patent's value by pushing the industry into a higher-rivalry state where firms deploy their patents in more aggressive competitive ways. This is a key prediction that impacts directly on the interplay between competition and cooperation and the balance between value creation at the industry level and firm-level appropriation: deploying a competitive advantage residing in patent technological strength aggressively in pursuit of value appropriation may invite rival responses that damage profit value creation and value maximization. The form of competition may also become more offensive (moving from patent wall to bracketing) as demand increases when the technology is strong. More interestingly, at medium technological strength, hybrid patent deployment strategies may result, e.g., involving competition via offensive bracketing at high demand and a switch to cooperation via licensing at low or medium demand, which implies a higher option value due to the ability to switch deployment modes -- especially when market volatility and the innovator's bargaining power are high. Further, the theory predicts that the value of the option to switch patent deployment modes is greater under the combination of three factors: when the innovator's technology is moderate in strength, its bargaining power is high, and market volatility is high. Under low market volatility, the current patent deployment mode is likely to persist across time periods. Also, under the above conditions licensing is more likely to occur when demand is either very high (possibly used in combination with self-commercialization) or low (used by itself), but not medium, suggesting that extreme demand volatility favors cooperation via licensing. That is, high demand volatility, increasing the range of extreme high and low demand states, makes licensing more beneficial. Conversely, low demand volatility would likely favor (game-theoretic) competitive patent deployment to exploit own technological advantage.

The remainder of this article is organized as follows: We first derive our theory's basic insights via a baseline numerical illustration using real option games. This approach aims to provide broad accessibility for a general audience and to incorporate a wide range of possible patent deployment options, such as commercializing the technology for own exclusive use, licensing the technology, cross-licensing patents, building a defensive patent wall or engaging in an offensive bracketing war.

The numerical analysis focuses on switching patent deployment modes across states (levels) of market demand at a given time. The next section supplements this inquiry with an extended analysis focused on switching patent deployment modes across time periods. To make the analysis tractable, we focus on a narrower range of just three deployment modes: commercializing the technology oneself (competition), licensing the patent to an incumbent (cooperation), or both concurrently (coopetition). The extended analysis is general in terms of method and parameter values, thus providing more rigorous sensitivity analysis and helping alleviate any concerns that our baseline numerical insights might be an artifact of specific parameter value choices. The final section discusses the broader implications of our study for theory, empirics, and practice. Details of our baseline numerical illustration and of our extended analysis are provided in Online Appendices A and B, respectively.

BASELINE NUMERICAL ILLUSTRATION: STRATEGIC PATENT DEPLOYMENT

In this section we provide a baseline numerical illustration of the patent deployment strategies of a technological innovator with a new patented technology facing an incumbent with an existing patented technology. Our analysis here focuses on switching between competition and cooperation modes depending upon the state of demand and the strength of the innovator's technology. By patent deployment we mean an innovative firm's set of choices about how to profit from its innovation and specifically which mode, if any, it chooses to deploy its patent – e.g., competition (via defensive patent wall or offensive patent bracketing), cooperation (via licensing the technology or cross-licensing patents), or delaying its choice of competition vs. cooperation until more information about market demand is revealed. We examine conditions where patent deployment strategies involve switching among these modes, as a function of demand shifts, demand volatility, and the relative strength of the innovator's new technology. We abstract away from other considerations, such as the need to prove the technology before licensing or facing high upfront and later declining technology integration costs that may justify pivoting from competition to licensing (Marx et al., 2014).

Assumptions

We consider a situation where two firms, firm T that innovates a new patented technology and incumbent firm I with an existing patented technology, are involved in a two-period strategic patent

deployment game. For simplicity, we here assume the innovator's patented technology results in one of three possible levels of technology improvement, labeled as weak, medium or strong technology, where a strong technology can improve the firm's competitiveness sufficiently to give it a monopoly position. The timing of the game is as follows:

- I. In period 0, innovative firm T patents a new superior technology. Assuming equal prior market power, this gives firm T an asymmetric cost advantage over firm I.
 - II. In period 1, the market experiences an initial demand shock that shifts demand either up or down.
 - III. In period 2, the market experiences a second demand shock that again shifts demand up or down.
- The cumulative effect of the two demand shocks leaves the industry in one of three possible demand states at time 2: low demand (two downward shocks), medium (one downward and one upward shock), or high demand (two upward shocks). Then each firm chooses its optimal patent deployment strategy (competing, cooperating or waiting), depending on innovative firm T's relative technology strength (weak, medium, or strong) and the observed realization of market demand (low, medium, or high). A final demand shock occurs at time 3, with demand thereafter assumed to remain in steady state, so any firm that chose the waiting option (patent sleep) during period 2 receives a continuation option value C .

Our baseline numerical analysis focuses on the Nash equilibrium deployment choices made by each firm in period 2 based on option games analysis (Chevalier-Roignant & Trigeorgis, 2011; Smit & Trigeorgis, 2004, 2017). We assume that both firms' technologies are publicly known and that patent rights are perfectly enforced. Expected cash flows are discounted across periods to determine current market value (the underlying "asset" for the options) by using the risk-adjusted cost of capital ρ while expected option values in the option games are based on risk-adjusted (or risk-neutral) probabilities and discounted at the risk-free interest rate r (Chevalier-Roignant & Trigeorgis, 2011; Smit & Trigeorgis, 2004, 2017).

Table 2 lists the parameters and parameter values used in our baseline numerical analysis. V is the total market value for the industry, computed as the (gross) present value of expected cash inflows from commercializing the patented technology. Its initial (current) value V_0 is the total market value at period 0, before any demand shocks, which we assume is \$100m. Parameters u and d are the

multiplicative factors specifying the magnitude of upward and downward movements for each demand shock (and hence the range of demand), with $\sigma = \ln u$ being the demand volatility, while p and $1-p$ are the risk-adjusted (or risk-neutral) probabilities of an upward and downward demand shock movement, respectively. V^{++} , V^{+-} , and V^{--} are, respectively, the three possible market values observable at time 2 after either two upward demand shocks (high demand), one upward and one downward shock (medium demand), or two downward shocks (low demand). Exercise mode factor m is a multiplier by which total market value is enlarged if the firms cooperate, or reduced if they compete aggressively. Under cooperation, we assume $m = c = 1.2$, where c refers to “cooperation.” Under competition, we assume $m = f = 0.7$, where f refers to “fight.” In terms of value capture, parameters s (for firm T), and $1-s$ (for firm I), represent the firms’ respective shares (based on relative market power) of the total market value V or the continuation option value C , which represents the expected payoff from waiting until one more period (and settling in steady state thereafter). As explained in Online Appendix A, these market power shares depend on the degree of firm T’s relative technology advantage.

Implementing a patent deployment strategy requires incurring an investment cost. Parameter I ($= \$80m$) is the baseline investment cost (e.g., for entry or integration) for a firm to commercialize its technology. (Under low demand, the cost is $I' = \$40m$.) This cost is shared if the two firms cooperate, is increased if they compete aggressively, or is delayed if they let their patents sleep. As noted, cooperation may take the form of either patent licensing or cross-licensing while competition may involve a defensive patent wall or offensive patent bracketing. Both competition modes increase the cost for the rival firms due to costly multiple patent filings, via a cost multiplier, while a patent wall also strengthens one’s market position, as reflected in a market value V increase implemented through a multiplier m . Each payoff at (maturity) time 2 thus takes the form of a conditional NPV of the general form $mV - zI$, where m and z are the value and cost multipliers, respectively.

The three possible patent technology strengths (weak, medium, and strong) combined with the three possible demand levels (low, medium, and high) at time 2 yield nine possible option-game scenarios, shown in Figure 1. For these nine scenarios, Figure 2 Panel A shows the nine corresponding subgames, numbered 1 through 9, that the two firms might play. In each subgame, each firm chooses

whether to invest in deploying its patent or to delay this investment, with the latter choice being labeled as “sleep.” An illustration of patent sleep is the case of Endovascular Technologies (EVT) and Guidant shown in Table 1. Keeping one’s patent sleeping amounts to delaying the deployment mode decision until next period (time 3). Holding a sleeping patent is a wait-and-see option that has more value when demand is volatile – specifically, continuation value C represents a call option on the period 3 market value. If both firms let their patents sleep, they appropriate portions of C in proportion to their market power shares, s and $1-s$. If a firm does not let its patent sleep, it can make four possible types of investment – ‘cooperative’ investment via patent licensing (unilateral) or cross-licensing (bilateral) versus ‘competitive’ investment via a patent wall (defensive) or bracketing (offensive). It is assumed that cooperation results in enlarged market value pie (here by 20%) as the collaborators capture and share monopoly-like profits by maintaining high prices. By contrast, aggressive competition (defensive or offensive) results in a reduced market value pie (here by 30%) due to the ensuing product market rivalry and costly patent wars.

Investing under a cooperative mode involves either unilaterally licensing out one’s patent to the rival, or cross-licensing patents with the rival when both firms invest. Under cross-licensing, both firms may still compete with each other in the product market while behaving cooperatively in the technology market. So, in a way cross-licensing may be interpreted as a form of coopetition as it combines elements of both cooperation and competition. The driving force of the sharing terms of collaboration among the firms is the relative market power based on the advantage of firm T’s patented technology relative to firm I’s. For example, if firm T’s technology is strong, it appropriates most ($s = 75\%$) of conditional period 2 NPV (of the form $mV - zI$) or C while firm I gets the remainder. If firm T’s technology is medium, it gets 60% while firm I gets 40%. If firm T has a weak technology advantage over firm I’s existing patented technology, sharing is assumed 50-50. Parameter F (expressed as a percentage of market value) is the licensing fee that a firm pays to the other when licensing its technology (F' is the licensing fee under low market demand).

Under competition, investing might involve either defensively building a wall of related patents surrounding one’s own core patent to protect against encroachment, or offensive patent

bracketing surrounding the rival's patent with one's own related patents to constrain the rival. To illustrate a patent wall, see the examples of Xerox vs. IBM and Gillette vs. BIC in Table 1. To illustrate bracketing, see Yamaha vs. Bombardier in Table 1. In our numerical analysis, the main difference between these two forms of competition is that a patent wall provides both costs and benefits, while a bracketing war incurs costs without tangible benefits. With a patent wall, the investment cost is higher, multiplied by $W_T (= 1.2)$ for firm T and by $W_I (= 1.3)$ for firm I, while the market value is also higher, multiplied by $W'_T (= 1.2)$ for firm T and by $W'_I (= 2.2)$ for firm I. If the two firms compete by engaging in an offensive patent bracketing war, their respective investment costs are increased to bI , where $b (= 1.3)$ is the bracketing cost multiplier, without any compensating tangible benefits.

In each of the nine subgames in Figure 2, some of these investment types are dominated by other types. So, to keep Figure 2 Panel A as simple as possible, we omit the dominated investment types. Thus, most of the subgames show only two possible types of investments – one investment type when only one firm invests, and another when both invest. For example, in subgame 3, when firm T's technology is strong and demand is high, the relevant investment is in a defensive patent wall if one firm invests, or in offensive bracketing if both invest – with both types being competitive investments. By contrast, at the opposite extreme, in subgame 7 where firm T's technology is weak and demand is low, the relevant investment is in licensing if one firm invests, or in cross-licensing if both invest – with both types being forms of cooperative investment. The most interesting case, as we analyze later, is in the middle, where the “hybrid” subgame 5 includes more than two possible investment modes that span across both competitive and cooperative investment types (bracketing when both firms invest and licensing when only one firm invests). The payoff formulas shown in Figure 2 Panel A are explained and derived in Online Appendix A (see Table A1). Each firm's payoff represents the value of net cash flows (or option value for patent sleep) generated by its chosen deployment strategy when met with its rival's strategy. We use these payoffs to determine what deployment strategies (competition, cooperation, or wait-and-see) the firms optimally pursue, depending on the strength of the innovator's new technology and the state and volatility of demand.

[INSERT FIGURES 1 AND 2 ABOUT HERE]

Overview of Method

For the remainder of this baseline numerical analysis, we substitute the parameter values from Table 2 into the payoff formulas in Figure 2 Panel A, which yields the numerical payoffs shown in Figure 2 Panel B that we use hereafter. The numerical analysis proceeds in several steps: First, innovative firm T's patent is valued using a conventional NPV analysis. Second, based on the strategic interactions between the two firms, the full value (Strategic NPV) of *strategically* exploiting the patent on the new technology is obtained via the 'option games' approach using binomial trees, based on the Nash equilibrium for each of the nine subgames (i.e., with each firm optimizing its choice conditional upon the other firm doing so as well). Based on these industry equilibria for each of the nine subgames in period 2 prevailing in different states of demand under different cases of technology strength, the initial (i.e., period 0) value of the patent strategy for innovator firm T is then determined by 'averaging out' the equilibrium payoffs across different demand scenarios and 'folding back' using option pricing based on the notion of strategic net present value (S-NPV), a valuation construct developed by Smit and Trigeorgis (2017). Beyond accounting for the traditional source of committed value captured in an NPV analysis (i.e., the value of expected discounted cash flows from preset operations and strategies), S-NPV captures the interplay among sources of value from commitment under competition (based on game theory) and flexibility under uncertainty (based on real options), yielding a more complete representation of the various value components and trade-offs from competing courses of action. Subsequently, sensitivity and robustness analyses are presented and discussed.

Analysis

We start with the conventional patent valuation for innovator firm T. Based on NPV, the patent's value for firm T is obtained by discounting its expected cash flows (net of "entry" cost I of \$80m) back to time $t = 0$ using the cost of capital ($\rho = 20\%$). Expectations are taken by assigning appropriate probabilities to each demand scenario at period 2, resulting in a gross present value of the patent cash flows V of \$100m. The static NPV of the patent is thus \$20m ($= V - I = 100 - 80$). This static analysis ignores the options embedded in the patent deployment game, which we address next.

The patent will have higher value if it can be used *strategically*, either against or to also benefit the competitor. In terms of the Nash equilibria of each subgame, Online Appendix A derives the firms' optimal patent deployment strategies at time 2 for each of the nine technology/demand combinations in Figure 2 Panel B. Three observations are noteworthy from this analysis. First, when there is weak technology advantage and rivals are symmetric in market power, cooperation is a natural equilibrium outcome: here firms cooperate via licensing or cross-licensing – see subgames 1, 4 and 7 in Figures 1 and 2. This is consistent with prior literature, which suggests that cross-licensing is appropriate when patent portfolios and players are similar in strength. Mihm et al. (2015) show that this holds when both firms are R&D leaders or both are R&D imitators. Such collaboration under symmetry is also observed in practice, as illustrated by the examples of IBM/Dell or Google/Samsung in Table 1.³

The second observation is that, at the opposite extreme, if the innovator's technology advantage is strong, the competition mode is more likely (subgames 3, 6 and 9 in Figures 1 and 2). As shown in Online Appendix A, the precise type of competitive patent strategy may differ across demand regimes – ranging from a wait-and-see strategy (patent sleep) in low demand to aggressive competition (e.g., patent wall or bracketing) in medium or high demand. This idea that the equilibrium changes when demand changes is also found in Cabral's (2000) textbook example of simultaneous entry with fixed cost. We view this result as an interesting case of that general principle – interesting because the form of competition becomes more offensive (i.e., moving from patent wall to bracketing) as demand increases under strong technology, as in the example of Yamaha and Bombardier in Table 1.⁴ Intuitively, when demand is intermediate and there is risk one of the firms will be preempted, firms follow a defensive competitive patent strategy by building a patent wall in hope of basic survival, but at higher levels of demand when both firms can readily survive, competition becomes more offensive (via bracketing) in an effort to attain higher duopoly gains.

³ In 2014, for example, Google and Samsung, both recognized as leaders in a diverse array of markets, signed a global patent cross-licensing agreement aimed at enhancing R&D cross-fertilization and reducing the potential for litigation. Their arrangement covered both existing and future (next 10 years) patents in an attempt to help each other shore up their respective technological weak spots in a global smartphone market with rapidly growing demand. Seungho Ahn, head of Samsung's IP Center, said that "Samsung and Google are showing the rest of the industry that there is more to gain from cooperating than engaging in unnecessary patent disputes."

⁴ As demand for personal watercraft grew rapidly, Yamaha bracketed its rivals by obtaining 100 patents on feature improvements around their designs. In 2001, it claimed Bombardier's new products infringed on its patents.

The third, and most interesting, observation is that under medium technological strength, hybrid patent deployment strategies may arise, e.g., involving competition via offensive bracketing at high demand and a switch to cooperation via licensing at low or medium demand. In case of medium technology strength under high demand (subgame 2 in Figures 1 and 2), each firm has a dominant strategy to invest involving a competition mode (again, see Yamaha vs. Bombardier in Table 1). However, under medium or low demand firms may switch to a cooperative mode via licensing (subgames 5 and 8 in Figures 1 and 2), as in the example of Genentech vs. Eli Lilly in Table 1.⁵ At medium demand the incumbent pursues a wait-and-see strategy, with the innovator licensing its moderately better technology to the incumbent for a fee while also producing for itself (a case of coopetition). We summarize the above analyses as follows:

Proposition 1 (form of competition): Under strong technology, competition prevails but the form of competition becomes more offensive (moving from patent wall to bracketing) as demand increases.

Proposition 2.1 (switching based on state of demand): Although an innovator will prefer the competition mode if its technology is strong and the cooperation mode if its technology is weak (unless market demand is very high), if its technology strength is medium the innovator will prefer a hybrid strategy that involves switching between competition at high market demand and cooperation at lower/medium demand levels.

Corollary 2.1a (licensing based on state of demand): An innovator will likely license its technology to an incumbent when neither its technology nor market demand are strong.

The circumstances around hybrid strategies are a novel aspect of this article as they give rise to deployment mode switching between competition and cooperation as a result of demand-side factors (shifts in market demand and, by extension, market volatility), independent of the supply-side considerations that prior research has focused on, such as uncertainty about the value of the technology and the (declining) cost of its integration (Marx et al., 2014) that may justify pivoting from competition to licensing/cooperation. So, in our model, switching can be in the reverse direction (i.e., from a cooperative to a competitive mode) if demand or volatility shifts are opposite, which is not explainable under the prior supply-side-based theory.

⁵ In the late 1970s, Genentech developed a synthetic insulin that in 1982 became the first-ever FDA-approved genetically engineered human therapeutic. Genentech licensed the related patent exclusively to incumbent Eli Lilly, rather than competing with it. Demand for synthetic insulin only grew slowly because any change in a diabetic patient's insulin can only be made cautiously at the discretion of a physician. Genentech's cooperative strategy, under medium demand conditions allowed both firms to profit in anticipation of subsequent demand growth.

We next show how the option-games valuation of the patent via strategic NPV (S-NPV) differs from a static NPV. Option-games valuation of firm T's patent deployment strategy depends on the equilibrium outcomes for each of the subgames composing the overall options game. The equilibrium outcome values under high, medium and low demand (E_H , E_M and E_L) provide the payoffs in the end-of-period nodes that are then folded back in a binomial option tree. Following Smit and Trigeorgis (2017), the period 2 equilibrium payoffs in each state of demand for a given technology strength (weak, medium, or strong) are then weighted by their respective (risk-adjusted) probabilities and discounted back to the present ($t = 0$) at the riskless interest rate r within the backward binomial process.

The period 2 equilibrium payoffs used for valuing the innovator's patent deployment strategy are those highlighted as shaded boxes in Figure 2 Panel B (first entry in each cell for the innovator firm T): in case of *weak* technology (subgames 1, 4 and 7) $E_H = 154$ (under high demand), $E_M = 25$ (under medium demand) and $E_L = 2$ (under low demand); for *medium* technology (subgames 2, 5 and 8) $E_H = 61$ (under high demand), $E_M = 46$ (under medium demand) and $E_L = 12$ (under low demand); for *strong* technology (subgames 3, 6 and 9) $E_H = 92$ (under high demand), $E_M = 34$ (under medium demand) and $E_L = 9$ (under low demand). As shown in Online Appendix A, the value of the patent deployment strategy, based on the S-NPV (see Smit & Trigeorgis, 2004, 2017) for innovator firm T, is \$32m in case of *weak* technology (following a cooperative licensing mode), \$31m in case of *medium* technology (following a hybrid strategy of competing under high demand, and cooperating via licensing under medium or low demand); and \$29m in case of *strong* technology (using bracketing under high demand, raising a patent wall under medium demand, and sleeping under low demand).

These results are summarized in Table 3. Compared to the static NPV of \$20m (which assumes investing now while foregoing the option to exploit the interplay between competition and collaboration after observing actual demand), firm T's patent option portfolio (estimated as Strategic NPV – static NPV) is worth \$12m under the cooperative strategy when the technology is *weak* (symmetry); \$11m under the hybrid strategy when the technology is *medium*; and \$9m under a competitive mode for *strong* technology. The competitive mode in this case, despite firm T's technological advantage, results in lower value due to value dissipation from the ensuing patent war.

In case of strong technology, firm T realizes that under high demand (H) it might be better off to cooperate (e.g., via cross-licensing), obtaining a smaller ($\frac{1}{2}$) share of a (20%) larger market pie (resulting in 154 as in subgame 1 in Figure 2 Panel B), rather than compete offensively shouldering higher bracketing costs to obtain a higher share ($\frac{3}{4}$) of a fiercely contested and (30%) smaller pie (resulting in value of 92 as in subgame 3 in Figure 2 Panel B). Such a switch from a competitive to a cooperative mode implies effectively replacing the equilibrium competitive payoff of 92 by the equilibrium cooperative payoff of 154 under strong technology. Such a hybrid patent strategy, switching from a compete mode (via defensive patent wall) in medium demand with room for just one firm to a cooperative mode in high demand results in a higher S-NPV of \$38m (up from \$29m), which nearly doubles the value of the patent option portfolio to \$18m. Such cooperative co-licensing of an industry standard is illustrated by the example of Philips and Sony in Table 1. This hybrid patent strategy under strong technology is more valuable (\$38m) than the cooperative strategy under weak technology involving symmetric firms (\$32m) or the hybrid strategy under medium technology (\$31m). Figure 3 shows how the value of the patent strategy (S-NPV) varies with technological strength, as reflected by market concentration (Herfindahl-Hirschman Index or HHI) at different levels of demand volatility (σ) under competitive, cooperative and hybrid patent strategies. The cooperation and hybrid strategies are at a higher (elevated) value level.

[INSERT TABLE 3 AND FIGURE 3 ABOUT HERE]

For robustness, we also consider how these numerical results shift in response to two main changes: First, in Online Appendix A, we examine how the results shift under the assumption of asymmetric prior market power in favor of incumbent firm I which offsets the technological advantage of innovator firm T. We find that cases that were previously symmetric, resulting in cooperation, now become asymmetric (due to prior advantage of the incumbent) switching to competition, and vice versa. What matters, therefore, is the *relative* overall competitive advantage (or firms' asymmetry), not just the technological advantage of the innovator. Second, we next examine the impact of changing the level of demand volatility. Figure 4 shows sensitivity of Strategic NPV to demand volatility (σ) under weak, medium and strong technological advantage. The base level of $\sigma = 60\%$ repeats the S-

NPV values shown in the middle column of Table 3. The conflict between competition and cooperation in high demand states leads to a value discontinuity (gap) between the rigid competitive strategy and the flexible cooperative (switch) strategy S-NPVs under strong technology. S-NPV values decline at lower volatility levels as expected by real options theory. At $\sigma = 15\%$, values coincide with those shown in the left S-NPV column in Table 3. An interesting discontinuity in the S-NPV values is noted around a critical volatility level of about $\sigma^* = 38\%$. This discontinuity arises due to a shift in certain subgame equilibria as volatility declines below a critical threshold level. Under strong technology, in low demand the equilibrium strategy is to sleep (wait) under high volatility; but as σ declines below σ^* , the value of the wait-and-see option declines while the appeal for the technologically advantaged firm T to compete (and drive the rival out) given low demand and recovery prospects rises. But at very high demand, cooperation is more attractive under high volatility, partly deriving from the option to jointly appropriate value and optimize under demand uncertainty, avoiding the prisoners' dilemma of both firms investing prematurely under the pressure of competitive rivalry. As volatility drops below a certain level, however, there is a switch from cooperative to competitive equilibrium (involving a shift from the sleep mode to a compete mode under low demand, and from the cooperate mode to a compete mode under high demand). Furthermore, under medium or high demand if technology is medium and volatility is high, future high rewards may induce the incumbent to compete aggressively and enter a bracketing war; as volatility declines, however, the possibility of high rewards declines and the incumbent may face a patent wall by the innovator or shift to cooperation. Figure 5 confirms, in the case of strong technology, that at low σ a rigid, compete-only strategy may be best. However, as the cone of uncertainty rises a wider menu of strategic deployment choices opens up, including sleep (and possibly exit) at the low end and cooperate at high (and possibly at middle) demand. At high volatility ($\sigma = 90\%$) patent deployment strategies thus span the whole range including sleep or exit, compete as well as cooperate strategy modes.

[INSERT FIGURES 4, 5, AND 6 ABOUT HERE]

Figure 6 provides an extension (including the case of weak and medium technology) of various cooperative vs. competitive patent deployment strategies that may be optimal when a broader (more

extreme) spread of demand states is possible. The case of strong technology (rightmost column) corresponds to the high volatility case (rightmost column) of Figure 5 above. Here, however, higher demand volatility allows adding extreme very high (VH) and very low (VL) demand states at the two tails, besides high (H), medium (M) and low (L) demand as in the base case. As previously, in determining the equilibria for each of the various cooperate or compete subgames, each firm would select the type of patent deployment strategy and associated options to optimally exercise depending on different market demand (and volatility) conditions and its relative technological strength. Under strong technology, patent deployment by firm T may span the entire menu of available options depending on prevailing market demand conditions: *exit* when demand is very low (VL); *sleep* or “wait and see” when demand is low (L); expand/strengthen the patent to compete (e.g., through a patent wall) at medium demand (M) while at times cooperate with the rival (e.g., to preempt third entrants); compete offensively (e.g., via *bracketing*) in high demand (H); and potentially switch to a cooperate mode at very high demand (VH) allowing both rivals to profit. Under strong technology the optimal patent strategy of firm T may vary or switch among defer (or exit) and compete or cooperate modes at a given time depending on the level of demand and other conditions such as volatility and industry dynamism. Under volatile conditions, patent deployment should be more flexible, able to adapt and switch among competitive, cooperative, or even coopetition modes, including delaying the commitment decision via a sleep mode. Patent deployment strategy is generally more hybrid (allowing more switching possibilities) when the innovator’s technology advantage is medium, with even small variations in demand (e.g., from high to medium) bringing about a strategy switch from a competitive to a cooperative mode involving licensing. The above insights can be summarized as follows:

Corollary 2.1b (licensing in volatile regimes): *Licensing can prevail in more volatile regimes, even when the innovator’s technology is strong, under very high demand when the (smaller) share of (larger) joint benefits from cooperation exceeds the dominant share of a reduced market pie from a costly patent war. High demand volatility, increasing the range of extreme high and low demand states, makes licensing more beneficial.*

Initially give-up (cooperate) strategies adopted at low or medium demand may switch to competition at high demand and then, at higher demand in volatile regimes, to cooperation. Volatility exacerbates these switching patterns between competition and cooperation.

EXTENDED ANALYSIS: PATENT DEPLOYMENT MODE SWITCHING OVER TIME

In this section, we extend the above baseline analysis of the tradeoff between competition and collaboration in patent deployment strategies to explicitly account for coopetition and for switching among deployment modes over time. To focus on these aspects and to keep the analysis tractable, we set aside some of the other features of the baseline numerical analysis. In the extension, only the innovator has a patented technology, eliminating the possibility of firms cross-licensing patents to each other. Consequently, we also set aside any notion of patent bracketing or patent wall. Further, to keep the analysis simple, we assume here that the incumbent always remains in the market. Finally, we make a specific assumption about the structure of the product market, namely firms simultaneously choose their output levels as in Cournot quantity competition (focusing on a process innovation). Details and derivations for this extended analysis are given in Online Appendix B.

The extended analysis considers an industry previously served only by an incumbent monopolist, firm I, over two subsequent time periods, 1 and 2, with linear demand for an undifferentiated product. Demand may shift between these two periods due to a demand shock, with equal probability of moving either up or down (as well as some probability of remaining at same level). Here, overall demand volatility is influenced by two factors: the likelihood of a demand shift occurring, i.e., the tail probability, and the magnitude of the shift if it occurs, i.e., the demand spread. Innovator firm T patents a new cost-saving technology whose strength reflects the magnitude of the reduction in the marginal cost. In each period ($t = 1$ or 2), firm T can deploy its patent in one of three ways: (1) It can pay a fixed capital cost to obtain the commercialization capability to produce at the lower marginal cost and engage in asymmetric Cournot competition with incumbent firm I, which must produce at its higher marginal cost (the “competition” deployment mode, abbreviated as P for “produce”). (2) It can license out its technology to the incumbent in a “gain sharing” licensing deal allowing firm I to also reduce its marginal cost by paying firm T a licensing fee consisting of a share of the incumbent’s incremental profit gain from using the licensed technology (a “cooperation” deployment mode, abbreviated as L for “license” only). (3) In a hybrid arrangement, firm T can both produce and license concurrently, with both firms enjoying the same lower marginal cost, while firm

T receives a licensing fee from the incumbent (the “coopetition” deployment mode, abbreviated as B for “both” producing and licensing concurrently). The innovator firm’s bargaining power in licensing negotiations is captured by the portion of the incumbent’s profit gain from using the superior technology that must be paid to the innovator as a licensing fee, under either the cooperation (L) or coopetition (B) deployment modes. The innovator firm T chooses whether to produce output in each period, whereas the incumbent firm I remains in the market for both periods.

[INSERT TABLE 4 ABOUT HERE]

As derived in Online Appendix B, Table 4 shows conditions under which innovator firm T will choose each of the three patent deployment modes (competition, cooperation, or coopetition) in a given time period, as a function of its technological advantage, the realized demand level, and its bargaining power in licensing negotiations. Table 4 Panel A represents our base case, based on the common situation where the innovator has moderate bargaining power, similar to Figure 1 from the baseline numerical illustration. In this case, cooperative deployment (i.e., licensing without producing) tends to prevail when the innovative firm’s technology is weak and market demand is not high, but the innovator will produce itself under the competitive mode when its technological advantage is strong or market demand is high, which make it worthwhile for the innovator to pay the fixed capital cost for producing in that period. The pattern in Table 4 Panel A is broadly in line with earlier Figures 1 and 6 (where competition prevails under very high demand even under weak technology). So, Proposition 2.1 and Corollary 2.1a from the baseline numerical analysis are reaffirmed.

Table 4 Panel B shows a less common case where the innovator has higher bargaining power in licensing negotiations, capturing more than half of the incumbent’s profit gain as a licensing fee. In this case, the coopetition mode (i.e., both producing and licensing concurrently) can prevail if market demand is sufficiently high. Otherwise, for lower levels of demand, the results of the high bargaining power case in Panel B are similar to the moderate bargaining power case from Panel A. This difference occurs because coopetition requires a trade-off in which the innovator sacrifices some product-market profits (i.e., giving up its asymmetric competitive advantage by allowing the incumbent rival also to use its superior technology) in exchange for licensing fees, and this trade-off is only worthwhile when

the innovator enjoys strong enough bargaining power to extract a majority of the incumbent's gains from licensing. As a result, when the innovator has high bargaining power, growth in demand can precipitate a switch from competition to coopetition, as in the case of LG's multiple relationships with Sony and Panasonic in the OLED TV market.⁶ We organize these *ex post* (period 2) results as follows:

Proposition 2.2 (switching based on state of demand – high bargaining power case): *When an innovator's bargaining power is high, higher demand may induce switching from competition to coopetition if the innovator's technology is strong, or from cooperation to coopetition if its technology is weak. For medium strength technology, patent deployment mode may switch from initially give-up strategies involving cooperation at low demand, to competition at medium demand and then at higher demand switch to coopetition.*

Bearing in mind that an innovator can license either with or without competing against the licensee – i.e., either in cooperation or in coopetition – the above proposition also implies the following corollary:

Corollary 2.2a (licensing based on state of demand – high bargaining power case): *When an innovator's bargaining power is high, it will prefer to license a weak technology always, a strong technology only when demand is high, and a technology of medium strength at the extremes of demand – i.e., when demand is either low (cooperation) or high (coopetition).*

The above *ex post* analysis examined conditions for *actual* switching among deployment modes at a given time in order to maximize the innovator's *realized* profit, as a function of the *level* of demand prevailing at that time – as well as other parameters such as the innovator's technological advantage and bargaining power. Next, we consider an *ex ante* analysis of conditions that increase the *probability* of switching at a *future* time to maximize the innovator's *expected* profit as a function of the *volatility* of demand and other parameters. Table 5 shows how a marginal increase in the probability of tail outcomes affects the *ex ante* probability of innovative firm T switching between different patent deployment modes (i.e., competition, cooperation, or coopetition) across time (i.e., between periods 1 and 2), depending on the spread of demand outcomes, the innovator's bargaining power, the strength of its technology, and the baseline demand. Panel A of Table 5 considers the base

⁶ In the early 2010s, amidst fierce competition between LG, Sony, Panasonic, and others in the end-product market for televisions, there were questions about the technology of the display panels that would be used in the next generation of smart TVs: Could the OLED panels that had been used in small devices like smartphones be scaled up to TV size in a cost-effective way? Under this cloud of uncertainty, an innovation race to develop this technology pitted LG against a partnership between rivals Sony and Panasonic. LG patented its OLED TV technology in 2012 and launched its own OLED TV product in 2013, just as Sony and Panasonic dissolved their partnership due to concerns about the commercial viability of the product and OLED TV demand. Within a few years as OLED TV demand grew rapidly, LG's OLED TV technology showed up in smart TV products by Sony and Panasonic that compete with LG's own smart TV products, thus switching from pure competition to a hybrid coopetition mode. Doing so might prevent rivals developing their own OLED technology and would avoid the risks of going it alone.

case with moderate bargaining power for the innovator, where increasing the probability of tail outcomes increases the probability of switching between cooperation and competition when the technology is weak or medium and the spread of demand outcomes is high. Panel B considers the less common case of high bargaining power where under high demand spread, increasing the probability of tail outcomes increases the probability of switching either between cooperation and competition if the technology is weak, or between competition and cooperation if the technology is strong, or in more complicated ways if the technology strength is medium, as we discuss next.

[INSERT TABLE 5 AND FIGURE 7 ABOUT HERE]

Figure 7 provides a more in-depth graphical representation of the *ex ante* results from Table 5, focusing on the cases where the technology strength is medium. We reduce the parameter space to just two dimensions for graphing purposes by setting the baseline demand and capital cost at reasonable typical levels. Along the bottom of the graph, where demand spread is zero, we find the innovator's initial (period 1, pre-shock) starting point (deployment mode), as a function of the technology advantage along the horizontal axis. When demand spread is zero, the outcome is non-switching, i.e., staying with the same deployment mode choice that the innovator makes in period 1. In period 1, the innovator starts in cooperation mode where the horizontal axis is in a red region, in competition mode where it is in a yellow region, and in cooperation where it is in a blue region. If the demand spread is close enough to zero in period 2 to remain in the red, yellow, or blue region, then no switching occurs among the two periods. When demand spread is sufficiently high in period 2 to move up into a different colored region, switching becomes possible. We start at the bottom of any dashed line, where no switches occur, and then follow the dashed vertical line upward to the point where we reach the threshold level of demand spread where switches can happen.

For the moderate bargaining power case in Panel A of Table 5 (corresponding to the baseline numerical illustration in the previous section), switching is relatively simple because there are only two possible types of switches, between competition and cooperation. On the left side, where the technology advantage is weak (below about 0.09), the red vertical dashed line shows that when demand spread is low enough to stay in the red region, no switching occurs away from cooperation,

but a positive probability of switching to competition (orange region) occurs when demand spread crosses into the orange region. On the right side, where technology advantage is medium or strong (above about 0.09), the yellow vertical dashed line shows that when demand spread is low enough to stay in the yellow region, no switching occurs from competition, but a positive probability of switching to cooperation occurs when demand spread crosses into the orange region. The situation is somewhat more involved in the less common case of Panel B where the innovator has higher bargaining power, as there are now six dashed vertical lines. The ones with very strong or weak technology involve simpler switches between two modes, while those in the middle region of technology strength involve possible switches among all three modes.⁷ Although Figure 7 provides a useful graphical illustration, it is limited to a single value of the baseline demand, which dictates a particular starting point in terms of deployment mode in period 1. So, to generalize to other possible values of the baseline demand, which would allow other starting points for the deployment mode, we turn our attention to Tables 4 and 5 (see also Tables B4 and B5 in Online Appendix B). From these tables, we make the following observations for the two cases.

In the more common base case when an innovator's bargaining power is moderate:

- 1) If the innovator starts in cooperation, which can occur when technology is not strong and baseline demand is not high, it will stay there in the next period if the demand spread is sufficiently low, but if demand spread is high it may switch to competition.

⁷ For example, the red vertical dashed line on the far left, at technology strength of 0.1, indicates that we start with cooperation in period 1 and do not switch in period 2 if demand spread is low enough to remain in the red region, but if demand spread crosses above the threshold into the purple region, then there is some probability of switching to competition in period 2. Panel B shows two other such simple two-region cases with only one type of switching: the second vertical line from the left (the blue one at technology strength of 0.25, where high spread makes switching from cooperation to competition possible) and the last vertical line on the far right (the yellow one at technology strength of 0.9, where high spread makes switching from competition to cooperation possible). Next, consider the three more involved cases in the middle, involving medium technology advantage, where each vertical line crosses three colored regions. On the second (thin) blue line at technology strength of 0.323, increasing spread first makes switching from cooperation to competition possible (green region), and then makes switching to cooperation possible at higher spread levels (purple region). On the thin yellow line at technology strength of 0.35, increasing spread first makes switching from competition to cooperation possible (green region), and then makes switching to either cooperation or competition possible at higher spread levels (brown region). On the thicker yellow vertical line at technology strength of 0.6, increasing spread makes switching from competition to cooperation possible (orange region), and then makes switching to either cooperation or competition possible for higher spread levels (brown region). In the region of medium technology strength, there are three even more involved cases where each vertical line crosses three colored regions. There is a distinction between the first one (thin blue line crossing green and purple regions) and the last two (yellow lines crossing brown region). In the first case, two different kinds of switches are possible, depending upon the value of demand spread – i.e., switch to competition for low values of demand spread, or to cooperation for high values – but only one type of switch for any given value of demand spread. By contrast, in the second and third cases, two different types of switches may occur at the same time, because it is possible to switch from competition to either cooperation or competition in the brown region.

- 2) If the innovator starts in competition, which can occur under strong technology or high baseline demand, it will stay there if demand spread is sufficiently low, but if demand spread is high it may switch to cooperation.

In the less common case when an innovator's bargaining power is high:

- 1) If the innovator starts in cooperation, which can occur when technology is not strong and baseline demand is not high, it will stay there in the next period if demand spread is sufficiently low, but if demand spread is high it may switch to either coopetition or competition depending on the technology strength, as follows:
 - a) For weak technology, it may switch to coopetition.
 - b) For technology of medium strength, it may switch to competition under moderately low baseline demand, or to coopetition under higher baseline demand.
- 2) If the innovator starts in coopetition, which can occur under high baseline demand, it will stay there in the next period if demand spread is sufficiently low, but if demand spread is high it may switch to either cooperation or competition depending on the technology strength, as follows:
 - a) For weak technology, it may switch to cooperation.
 - b) For strong technology, it may switch to competition.
 - c) For technology of medium strength, it may switch to competition under somewhat lower (moderately high) baseline demand, or to cooperation under lower baseline demand.
- 3) If the innovator starts in competition, which can occur either when technology is strong and demand is not high or when technology and demand are both medium, it will stay there in the next period if demand spread is sufficiently low, but if demand spread is high it may switch to either cooperation or coopetition depending on the technology strength, as follows:
 - a) For strong technology, it may switch to coopetition, as in the case of the 2004 formation of a joint venture between rivals Samsung and Sony.⁸

⁸ As the TV technology changed from analog to digital driving upward the volatility of the smart TV market, in 2004 Samsung and Sony established a JV (S-LCD), involving a cross-licensing of their respective patents, to develop seventh-generation LCD panels. While collaborating through cross-licensing, Samsung and Sony were simultaneously competing in the flat screen TV market.

- b) For medium strength technology, it may switch to either cooperation or coopetition, as in the case of Yahoo! and Facebook.⁹

We can summarize the essence of the results in these tables as follows:

Proposition 3 (demand volatility and switching across time): Under high demand volatility, an increased probability of extreme tail outcomes increases the probability of switching across time periods among competition, cooperation or coopetition. Under moderate bargaining power for the innovator (and weak or medium technology), it increases switching among cooperation and competition. When bargaining power is high, it increases switching between cooperation and coopetition under weak technology and between competition and coopetition under strong technology. When technology is medium (and bargaining power is high), it increases switching from any of the three deployment modes available to either of the other two modes. Switches can occur in either direction depending on technology strength and demand conditions.

The above *ex ante* results also provide insights for the flexibility versus commitment trade-off since they have implications for the conditions that affect the value of the option to switch deployment modes across time periods, rather than committing irrevocably to a specific deployment mode in period 1. The value of this kind of flexibility is illustrated by Motorola's failure when it irrevocably committed to licensing prior to a volatility increase.¹⁰ This flexibility would be worthless in conditions where the innovator would never choose to switch, regardless of the actual demand realized in period 2 (anywhere in the red, yellow, and blue regions in Figure 7). That is, flexibility would have no value if there are no switches that the innovator might want to do in period 2. At the opposite end, flexibility has the most value when there are multiple different types of switches that the innovator might want to do in period 2 (e.g., anywhere in the brown region of Figure 7 Panel B, where the innovator can switch from competition to either cooperation or coopetition, depending on actual demand realized in period 2).¹¹ This outcome occurs under high innovator bargaining power, medium technology strength, and high volatility, so:

⁹ As the online market volatility increased in the early 2000s, Yahoo! switched to a new, content-driven strategy (e.g., Yahoo! Music, Yahoo! Updates) to profit from online users and compete with Facebook along the lines of its emerging business model. Following Yahoo!'s lawsuit over patents for websites and web services in 2012, Facebook agreed with Yahoo! to cross-license each other's patent portfolios, thus resulting in a switch to a coopetition mode between the two companies. However, Facebook's fast growth later compelled Yahoo! to downsize its social networking strategy.

¹⁰ In 2001 Motorola committed to license its GSM technology to direct competitors Nokia and Ericsson to speed up industry growth. Following a rise in volatility of consumers' demand for smartphones, Motorola lost \$4.3 billion between 2007 and 2009 and was acquired in parts by Google (Motorola Mobility) and Nokia (Motorola Solutions).

¹¹ In 2002, P&G, while still fiercely competing with Clorox in several household goods markets, agreed to license to its rival its moderately superior wrap technology (developed earlier for use in the diaper and feminine-care products) to benefit from the demand change in the lucrative bags-and-wraps market.

Proposition 4 (value of option to switch modes across time): *The value of the innovator's option to switch patent deployment modes across time is greater when it enjoys high bargaining power in licensing negotiations, when its technology is of medium strength, and when demand volatility is high.*

IMPLICATIONS AND CONCLUSIONS

Choices about how to deploy a patent involve the two classic trade-offs of competition vs. cooperation (Brandenburger & Nalebuff, 1996) and flexibility vs. commitment (Ghemawat & del Sol, 1998). Our analysis indicates that although stronger technology makes an innovator more likely to compete, this competition may be blended with cooperation (i.e., coopetition) when market demand and the innovator's bargaining power are both high. Likewise, although weaker technology makes an innovator more likely to cooperate via licensing, high demand may induce it to compete – again leading to coopetition when it enjoys high bargaining power. With medium strength technology, an innovator may switch between cooperation and competition or do both concurrently, depending on demand. Indeed, an innovator with a medium-strength technology has a particularly strong incentive to be flexible in its patent deployment strategy when its bargaining power is high. In such a case, all three modes of competition, cooperation, and coopetition can be optimal at different levels of demand, and licensing is preferred at the extremes of demand – either low demand (in cooperation) or in high demand (in coopetition, while also competing against the licensee). Since this case is where the greatest variety of optimal patent deployment modes can occur, it is also where volatility has the greatest impact on the option value of the innovator's flexibility to switch modes over time. Thus, our analysis supports the logic of Lado, Boyd, and Hanlon (1997) that successful firms “possess enhanced *strategic flexibility* by either holding or striking a wide variety of *strategic options*.”

Several of our above findings contribute to research on patent deployment strategies. First, although a strong technology makes an innovator more likely to pursue a competitive patent deployment mode, it may combine competition with cooperation via licensing – i.e., deploy a coopetition strategy – when market demand and the innovator's bargaining power in licensing negotiations are high. Similarly, although weak technology makes an innovator more likely to pursue cooperation via licensing, sufficiently high demand may also induce it to compete – also leading to coopetition when the innovator enjoys high bargaining power. Second, the form of competition may

also become more offensive (moving from patent wall to bracketing) as demand increases when the technology is strong. Third, we find that an innovator with medium-strength technology may switch between cooperation and competition, or doing both concurrently, depending on the state of market demand and other conditions such as entry cost and relative bargaining power. Specifically, when bargaining power is moderate, it would likely switch from cooperation at low demand to competition at higher demand levels, and vice versa, but when bargaining power is high, any of the three deployment modes may prevail – cooperation for low demand, competition for medium demand, and cooperation for high demand. So, if bargaining power is high, we may observe switching between cooperation and cooperation when the innovator's technological advantage is weak, between competition and cooperation when the advantage is strong, and between all three deployment modes when the technology advantage is medium.

Finally, our analysis also has implications for the conditions affecting the option value of the flexibility to switch among deployment modes across time periods and for the impact of demand volatility on the probability of such switches. Generally, the value of the innovator's option to switch is greatest when it may have an incentive to switch into multiple patent deployment modes. Such switching is more likely when the innovator enjoys high bargaining power, when technology strength is medium, and when demand volatility is high. Higher demand volatility, increasing the range of extreme low and high demand states, exacerbates these switching patterns between competition and either cooperation or cooperation, rendering licensing more beneficial in both very high and low demand states. The above contributions complement and contrast with work in the innovation literature (e.g., Marx et al., 2014) that focuses on supply-side drivers of patent deployment strategy.

Implications for Future Research

The result that cooperation or cooperation may prevail in high-demand conditions may help explain why such approaches to commercializing a strong technological innovation might prevail in dynamic environments that entertain the prospect of *very* high levels of demand. Our analysis suggests that if the firm follows a cooperation or cooperation strategy, the joint benefits from cooperation enlarging the market pie may exceed the value from a higher share of a smaller market pie from

competing aggressively. A strong technological advantage may also induce patent sleeping (or rival exit) under very low demand, as in EVT's selloff of its sleeping patented coronary stent technology to Guidant. All of these results merit further consideration and additional research.

Our analysis also reveals severe limitations of traditional NPV that treats the size of the market pie as given, and suggests that future research should adopt strategic net present value (S-NPV) analysis instead. In option-games analysis, firm decisions are contingent on both market demand and rivals' reactions to one's own patent deployment moves. The size and sharing of the market pie are a function of competition, cooperation, or hybrid coopetition strategies pursued by the firm and its rivals, moderated by the level and volatility of demand. Pursuing a competitive strategy may potentially lead to lower overall value due to ensuing patent wars, despite a considerable technological advantage. Hence, the value of a patent deployment strategy may be enhanced by a combination of favorable market conditions and via a cooperation or coopetition approach under high demand and volatility conditions. Even in low demand with a weak or medium technology advantage, the value of the associated patent strategy may be enhanced via licensing in light of future collaboration.

Another insight worthy of future examination is that demand volatility and extreme outcomes can be value-enhancing as they not only increase growth option value but can also induce firms to switch to a cooperation or coopetition strategy, which reduces the incentive to win at any cost. This hidden potential from high demand volatility often occurs when firms are roughly symmetric with equivalent technologies (e.g., Google and Samsung). High demand volatility and extreme tail outcomes can motivate a richer set of switching patterns between competition and cooperation or coopetition, which is particularly relevant in emerging or dynamic technology industries (Ang, 2008). Additional research is needed to test these predictions and better understand their boundary conditions.

Implications for Practice

Our analysis also offers practical implications to IP managers for a more adaptive patent deployment strategy, by identifying conditions that justify pivoting among competition, cooperation, and coopetition modes. For example, a hybrid coopetition mode makes sense if market demand and the innovator's bargaining power are very high. Under high enough bargaining power to appropriate

most of the gains from innovation, licensing out the technology makes sense when demand is either low or very high (where licensing is combined with self-commercialization), so extreme demand volatility favors licensing. More generally, the use of option games in strategic decisions gives managers a tool to assess the value of patents and other strategic investments under both demand and strategic uncertainty. Strategic NPV analysis enables managers to address concurrently the competition vs. cooperation and the flexibility vs. commitment trade-offs within a single holistic framework and provide insights on strategy mode switching and path dependency. Such analysis depends on some well-known factors, such as the strength of the new technology, relative market or bargaining power and anticipated rival reactions, but also on some less obvious factors like the demand and volatility regimes, which may help explain more subtle differences in strategic investment behavior. Our results also highlight the importance of maintaining a flexible IP portfolio strategy and attracting the right collaborations (Grindley & Teece, 1997). Creating and managing cooperative relationships, leveraging (“borrowing”) resources outside firm boundaries (Capron & Mitchell, 2012) within a broader alliance portfolio that is “evolving from adapting to shaping and exploiting, according to the state of strategic uncertainty” (Hoffmann, 2007) is a critical dynamic capability. Management should thus be flexible to dynamically switch among wait-and-see, competition, cooperation, or coopetition strategy modes as market circumstances warrant.

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References

- Ang, S.H. 2008. Competitive intensity and collaboration: impact on firm growth across technological environments. *Strategic Management Journal*, 29(10): 1057-1075.
- Arora, A. 1997. Patents, licensing, and market structure in the chemical industry. *Research Policy*, 26(4): 391-403.
- Arora, A., & Ceccagnoli, M. 2006. Patent protection, complementary assets, and firms' incentives for technology licensing. *Management Science*, 52(2): 293-308.
- Arora, A., & Fosfuri, A. 2003. Licensing the market for technology. *Journal of Economic Behavior & Organization*, 52(2): 277-295.
- Arora, A., Fosfuri, A., & Gambardella, A. 2004. *Markets for Technology: The Economics of Innovation and Corporate Strategy*. Cambridge, MA: MIT Press.
- Arundel, A., & Patel, P. 2003. Strategic patenting. *Background report for the Trend Chart Policy Benchmarking Workshop: New Trends in IPR Policy*: Luxembourg.
- Bar-Ilan, A., & Strange, W.C. 1998. A model of sequential investment. *Journal of Economic Dynamics and Control*, 22(3): 437-463.
- Brandenburger, A., & Nalebuff, B. 1996. *Co-opetition*. New York: Doubleday.
- Cabral, L.M.B. 2000. *Introduction to Industrial Organization*. Cambridge, MA: MIT Press.
- Calabrese, T., Baum, J.A.C., & Silverman, B.S. 2000. Canadian biotechnology start-ups, 1991–1997: The role of incumbents' patents and strategic alliances in controlling competition. *Social Science Research*, 29(4): 503-534.
- Capron, L., & Mitchell, W. 2012. *Build, Borrow, or Buy: Solving the Growth Dilemma*. Boston: Harvard Business Review Press.
- Ceccagnoli, M. 2009. Appropriability, preemption, and firm performance. *Strategic Management Journal*, 30(1): 81-98.
- Chevalier-Roignant, B., & Trigeorgis, L. 2011. *Competitive Strategy: Options and Games*. Cambridge, MA: MIT Press.
- Clark, D.J., & Konrad, K.A. 2008. Fragmented property rights and incentives for R&D. *Management Science*, 54(5): 969-981.
- Cohen, W., Nelson, R., & Walsh, J. 2000a. Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). *NBER Working Paper Series*: 7552.
- Cohen, W.M., Nelson, R.R., & Walsh, J. P. 2000b. Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not). *National Bureau of Economic Research Working Paper Series*, No. 7552.
- DeLacey, B.J., Herman, K., Kiron, D.J., & Lerner, J. 2006. Strategic Behavior in Standard-Setting Organizations, *Harvard NOM Working Paper No. 903214*. Available at SSRN: <https://ssrn.com/abstract=903214> or <http://dx.doi.org/10.2139/ssrn.903214>.
- Dierickx, I., & Cool, K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science*, 35(12): 1504-1511.
- Gans, J.S., Hsu, D.H., & Stern, S. 2002. When does start-up innovation spur the gale of creative destruction? *RAND Journal of Economics*, 33(4): 571-586.
- Gans, J.S., & Stern, S. 2003. The product market and the market for “ideas”: commercialization strategies for technology entrepreneurs. *Research Policy*, 32(2): 333-350.

- Ghemawat, P., & del Sol, P. 1998. Commitment versus flexibility? *California Management Review*, 40(4): 26-42.
- Granstrand, O. 1999. *The Economics and Management of Intellectual Property: Towards Intellectual Capitalism*. Cheltenham, UK: Edward Elgar Publishing.
- Grindley, P.C., & Teece, D.J. 1997. Managing intellectual capital: Licensing and cross-licensing in semiconductors and electronics. *California Management Review*, 39(2): 8-41.
- Hall, B.H., & Ziedonis, R.H. 2001. The patent paradox revisited: An empirical study of patenting in the U.S. semiconductor industry, 1979-1995. *RAND Journal of Economics*, 32(1): 101-128.
- Heller, M.A., & Eisenberg, R.S. 1998. Can patents deter innovation? The anticommons in biomedical research. *Science*, 280(5364): 698-701.
- Hill, C.W.L. 1992. Strategies for exploiting technological innovations: When and when not to license. *Organization Science*, 3(3): 428-441.
- Hoffmann, W.H. 2007. Strategies for managing a portfolio of alliances. *Strategic Management Journal*, 28(8): 827-856.
- Hoffmann, W.H., Lavie, D., Reuer, J.J., & Schipilov, A. 2018. The interplay of competition and cooperation. *Strategic Management Journal*, 39(12): 3033-3052.
- Hounshell, D., & Smith, J. 1988. *Science and Corporate Strategy: Du Pont R&D, 1902-1980*. Cambridge, MA: Cambridge University Press.
- Lado, A.A., Boyd, N.G., & Hanlon, S.C. 1997. Competition, cooperation, and the search for economic rents: A syncretic model. *Academy of Management Review*, 22(1): 110-141.
- Levin, R.C., Klevorick, A.K., Nelson, R.R., & Winter, S.G. 1987. Appropriating the Returns from Industrial Research and Development. *Brookings Papers on Economic Activity*, 1987(3): 783-831.
- Levitt, T. 1965. Exploit the product life cycle. *Harvard Business Review*, 43(November): 81-94.
- Marx, M., Gans, J.S., & Hsu, D.H. 2014. Dynamic commercialization strategies for disruptive technologies: Evidence from the speech recognition industry. *Management Science*, 60(12): 3103-3123.
- McGahan, A.M. 2004. *How Industries Evolve: Principles for Achieving and Sustaining Superior Performance*. Boston: Harvard Business School Press.
- Mihm, J., Sting, F.J., & Wang, T. 2015. On the effectiveness of patenting strategies in innovation races. *Management Science*, 61(11): 2662-2684.
- Polidoro, F., & Toh, P.K. 2011. Letting rivals come close or warding them off? The effects of substitution threat on imitation deterrence. *Academy of Management Journal*, 54(2): 369-392.
- Reitzig, M. 2004a. The private values of 'thickets' and 'fences': towards an updated picture of the use of patents across industries. *Economics of Innovation and New Technology*, 13(5): 457-476.
- Reitzig, M. 2004b. Strategic management of intellectual property. *MIT Sloan Management Review*, 45(3): 35-40.
- Rivette, K., & Kline, D. 2000a. Discovering new value in intellectual property. *Harvard Business Review*, 78(1): 54-66.
- Rivette, K., & Kline, D. 2000b. *Rembrandts in the Attic: Unlocking the Hidden Value of Patents*. Boston: Harvard Business School Press.
- Rubinfeld, D. L., & Maness, R. 2005. The Strategic Use of Patents: Implications for Antitrust. In F. Lévêque, & H.A. Shelanski (Eds.), *Antitrust, Patents, and Copyright: EU and US Perspectives*: 85-102. Cheltenham, UK: Edward Elgar Publishing.

- Shapiro, C., & Varian, H.R. 1999. *Information Rules: A Strategic Guide to the Network Economy*. Boston, MA: Harvard Business School Press.
- Smit, H.T.J., & Trigeorgis, L. 2004. *Strategic Investment: Real Options and Games*: Princeton, NJ: University Press.
- Smit, H.T.J., & Trigeorgis, L. 2017. Strategic NPV: Real options and strategic games under different information structures. *Strategic Management Journal*, 38(13): 2555-2578.
- Somaya, D. 2003. Strategic determinants of decisions not to settle patent litigation. *Strategic Management Journal*, 24(1): 17-38.
- Teece, D.J. 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy. *Research Policy*, 15(6): 285-305.
- Walsh, J.P., Arora, A., & Cohen, W.M. 2003. Effects of Research Tool Patents and Licensing on Biomedical Innovation. In W.M. Cohen, & S.A. Merrill (Eds.), *Patents in the Knowledge-Based Economy*: 285-340. Washington, DC: National Academies Press.
- Weeds, H. 1999. Sleeping Patents and Compulsory Licensing: An Options Analysis, *University of Warwick Department of Economics Working Paper Number 577*.

FIGURE 1. Patent Deployment Strategies (Compete or Cooperate) Contingent on Technology Strength and State of Demand (for Medium/Base Uncertainty $\sigma = 60\%$) in the Numerical Illustration

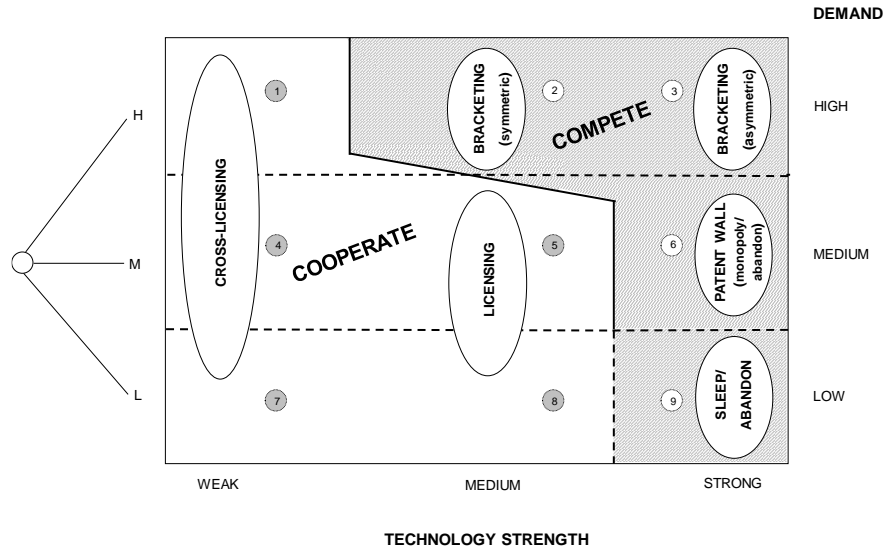


FIGURE 2 Panel A. Subgame Payoffs Depending on Demand and Technology Strength

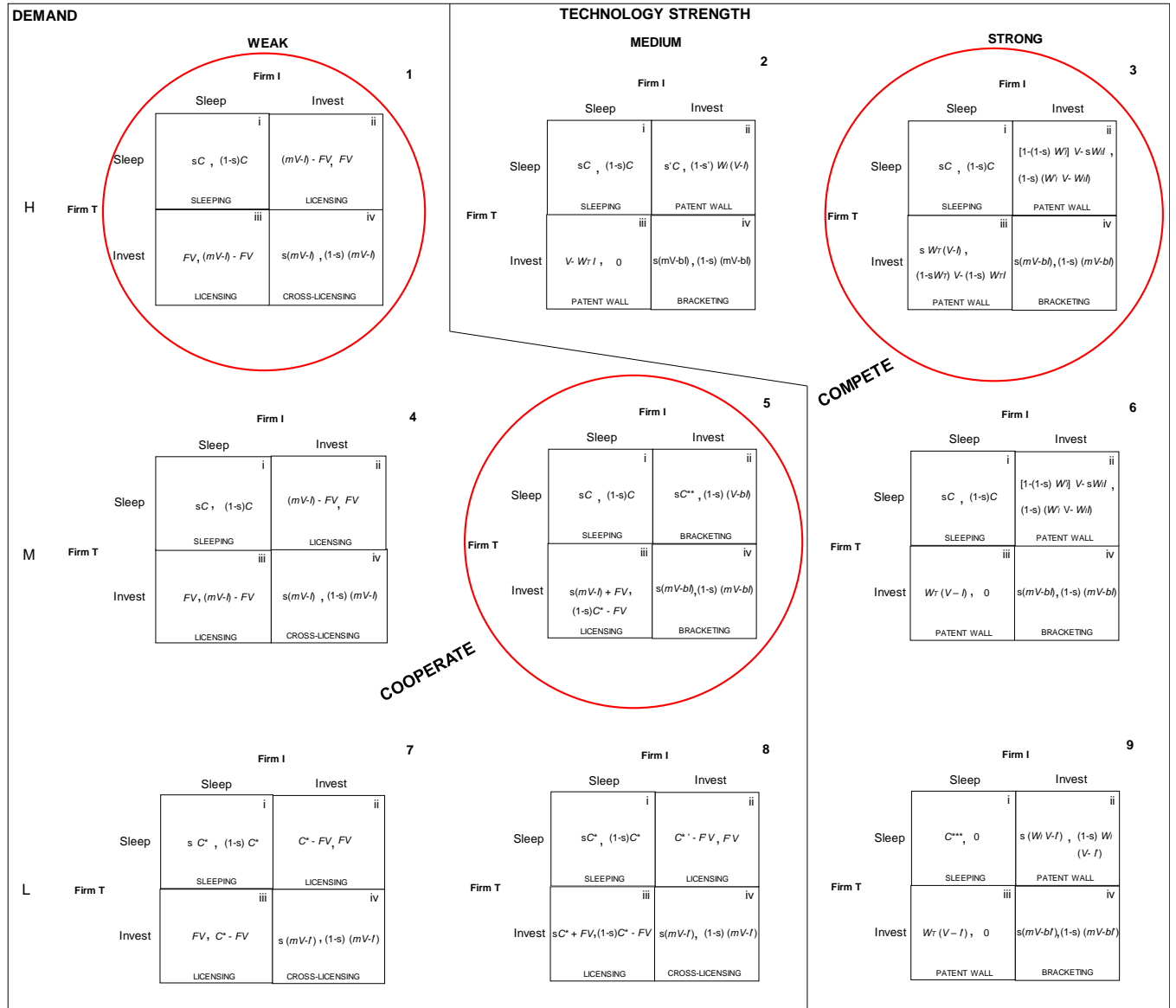


FIGURE 2 Panel B. Subgame Nash Equilibria Using Parameter Values from Table 2

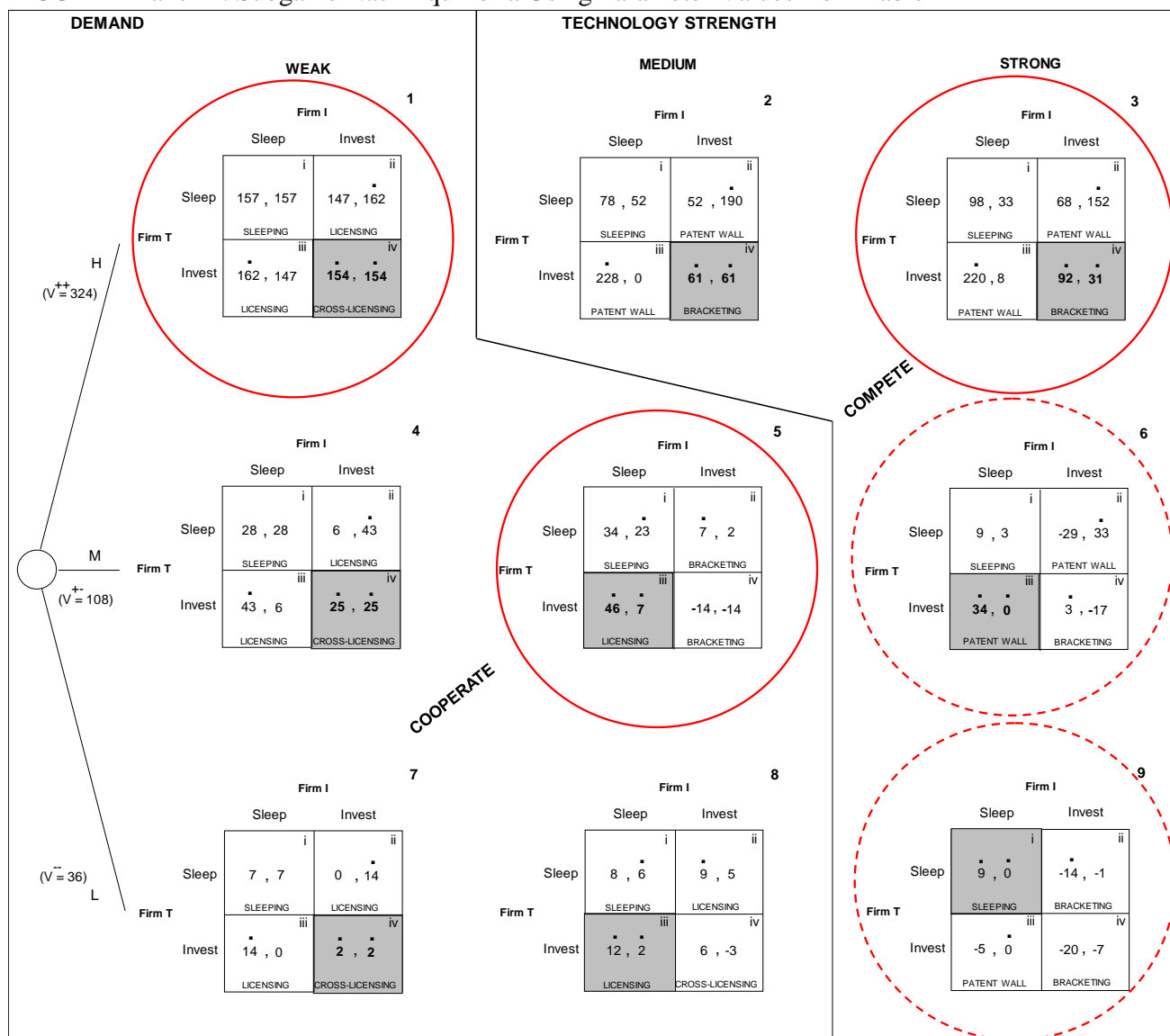


FIGURE 3. Value of Patent Strategy (S-NPV) in the Numerical Illustration for Varying Degrees of Technology Strength (Proxied by the Market Concentration Index HHI) and Different Volatility, under Competitive, Cooperative and Hybrid/Flexible Strategy (Symmetric Duopoly)

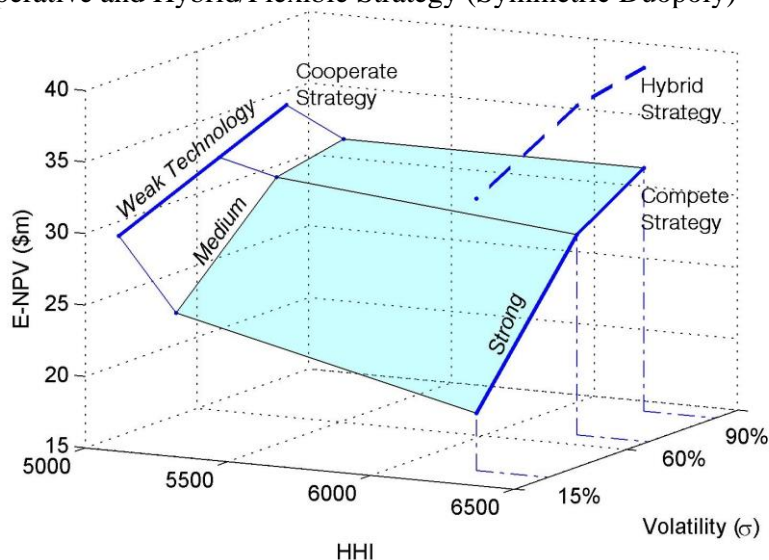


FIGURE 4. Sensitivity of S-NPV to Volatility under Weak, Medium, or Strong Technology in the Numerical Illustration

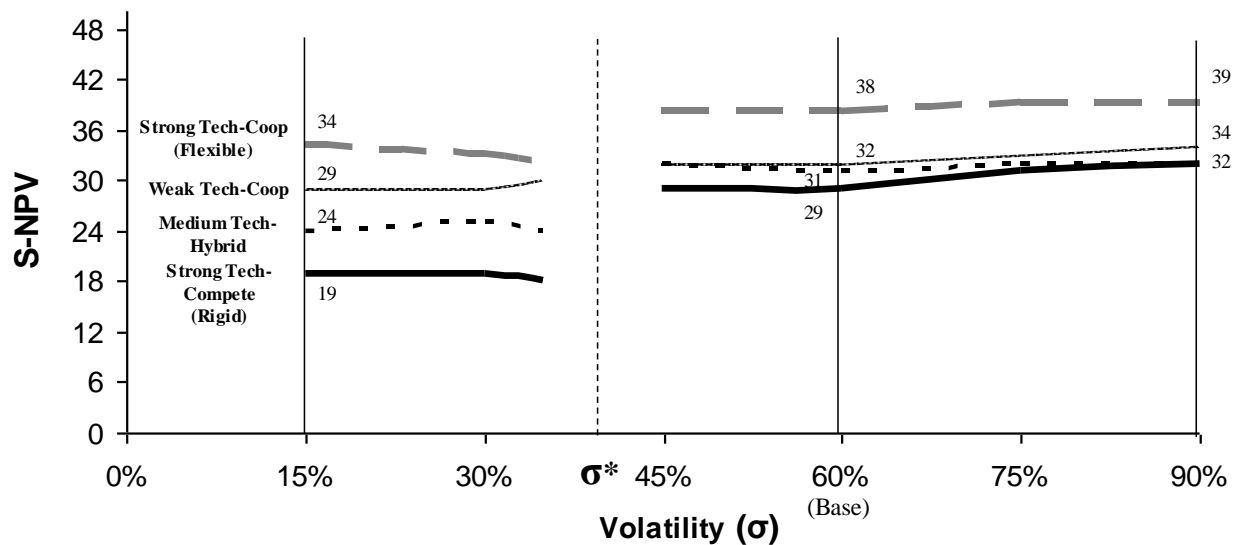
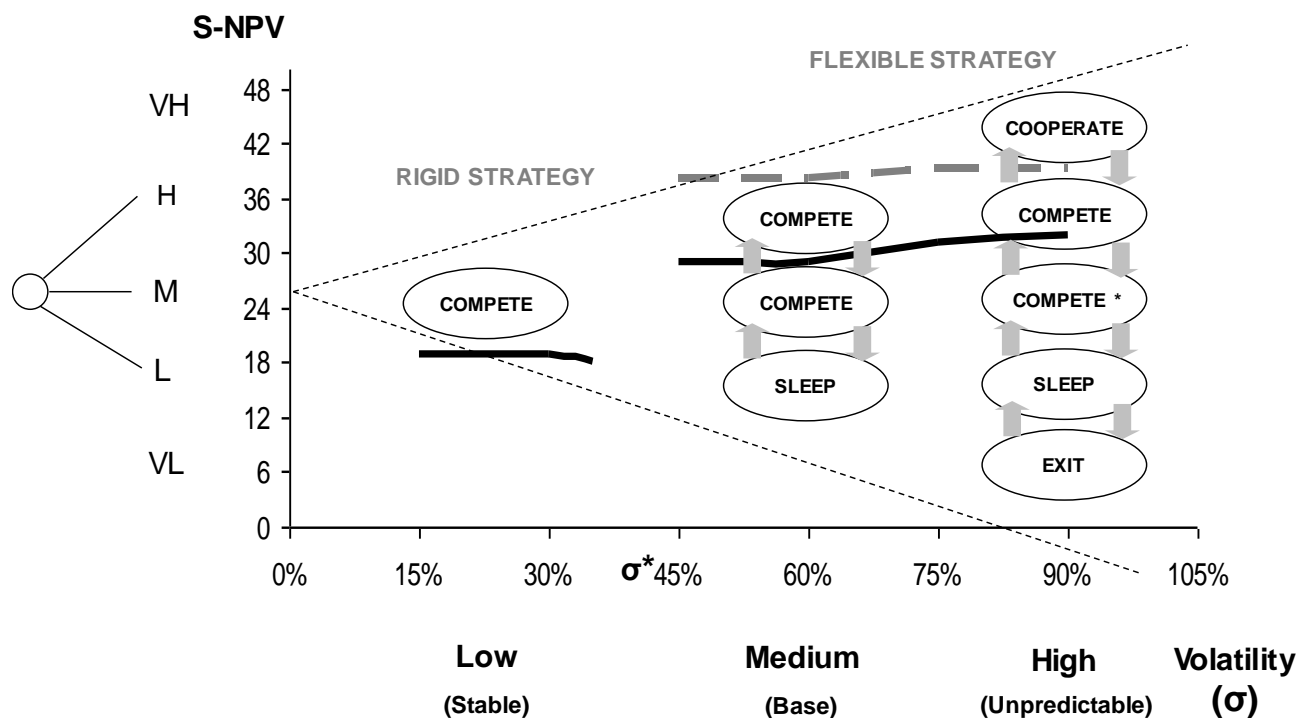


FIGURE 5. Summary and Extension of Patent Deployment Strategies in the Numerical Illustration for a Broader Range of Demand/Uncertainty (Under Strong Technology) – Symmetry Case



* Sometimes cooperate (e.g., cross-licensing against third rivals)

FIGURE 6. Extension of Compete vs. Cooperate Strategies in the Numerical Illustration (for a Broader Range of Demand/Uncertainty) under Weak, Medium or Strong Technology

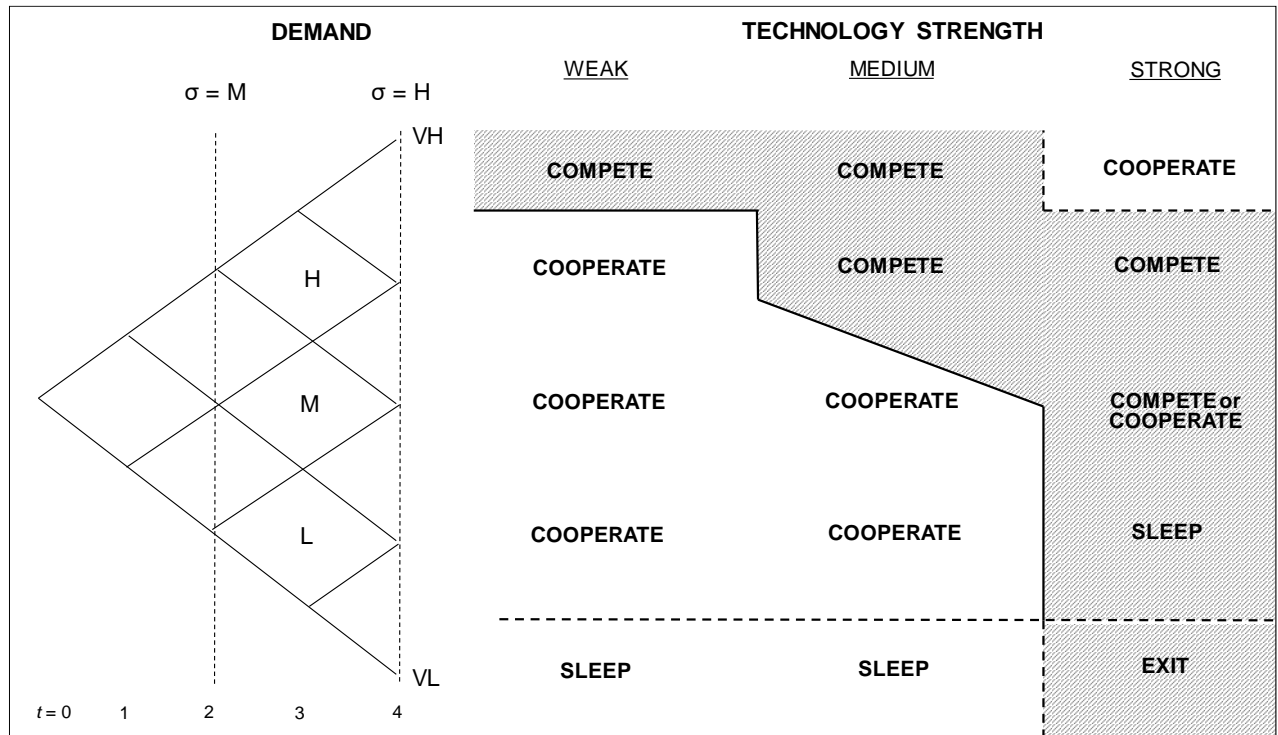
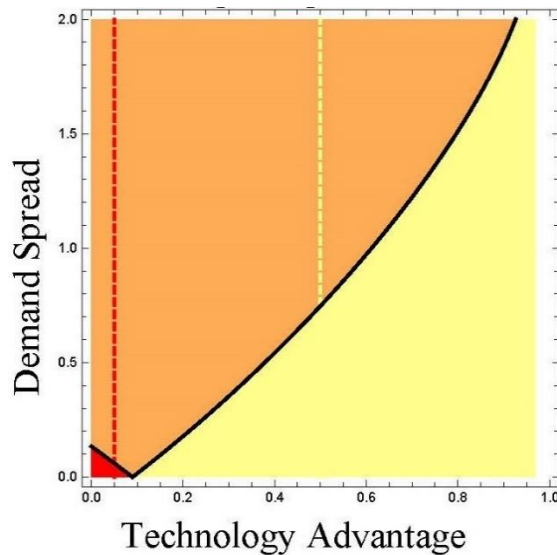
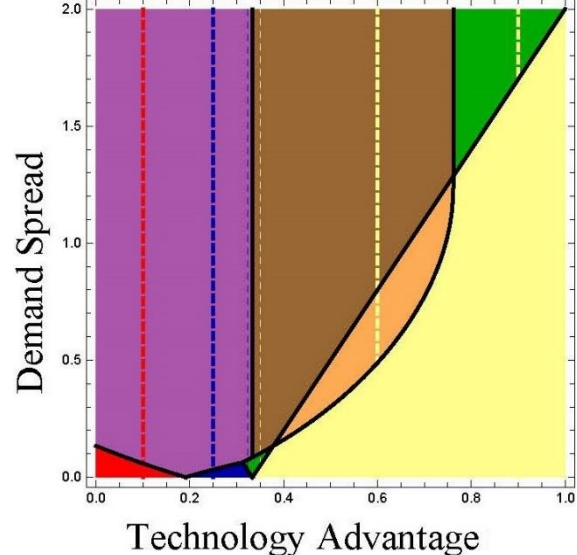


FIGURE 7. Switching Probabilities as a Function of Technology Advantage and Demand Spread, Under Either Moderate (Panel A) or High (Panel B) Innovator Bargaining Power

Panel A: Moderate Bargaining Power



Panel B: High Bargaining Power



Ex Ante Probabilities

- Competition only (zero probability of switching)
- Cooperation only (zero probability of switching)
- Cooperation only (zero probability of switching)
- Probability γ of switching between Competition and Cooperation
- Probability γ of switching between Competition and Cooperation
- Probability γ of switching between Cooperation and Competition
- Probability γ of switching among Competition, Cooperation, and Cooperation

TABLE 1. Real-World Business Examples of Compete and Cooperate Patent Deployment Strategies

Technology	Demand	Volatility	Mode	Form	Real-world Business Example
Panel A. Cooperate					
Weak	High	Medium/ High	Cooperate (against externals)	Cross- Licensing	In 2014 Google and Samsung signed a 10-year cross-licensing agreement enabling each to access each other's patent portfolios on products and technologies in response to Rockstar Consortium (Apple, Microsoft and Sony) suing rivals.
Panel B. Cooperate/Compete (Hybrid)					
Medium	Low/ Medium	High	Cooperate	Licensing	In 1970s Genentech cooperatively licensed its patent on synthetic "human" insulin to Eli Lilly (incumbent) enhancing both firms' advantage in the industry as post-innovation monopoly profits exceeded combined duopoly profits.
Medium/Strong	High	High	Compete	Patent Bracketing	In 1990s, as demand for personal watercraft grew rapidly, Yamaha bracketed its rivals by obtaining 100 patents with feature improvements around their designs. In 2001 it claimed Bombardier's new products infringed its patents.
Panel C. Compete					
Strong	Low	Medium	Wait	Patent Sleep	In 1989 EVT patented its Ancure stent system and kept the patent sleep (in low-demand coronary market). In 1997 Guidant (new entrant) responded to incumbent Johnson & Johnson (J&J)'s patent infringement suit acquiring EVT and its dormant stent technology. In 6 months Guidant sold \$350 m worth of devices.
Strong	Medium	Low (stable)	Compete	Patent Wall	In late 1960s Xerox blocked rivals by patenting every feature of its copier technology "xerography". When IBM tried to enter in 1972, Xerox sued, blocking entry with hundreds of patents (until antitrust authorities intervened).
Strong	Medium	Medium	Compete	Patent Wall	In 1990, after BIC's challenge with disposable razors, Gillette launched <i>Sensor</i> cartridge razors (emphasizing comfort over price) protected by a patent wall. <i>Sensor</i> became the best-selling cartridge razor in US. Walls of 35 and 70 patents defended later launches of <i>MACH3</i> and <i>Fusion</i> in 1998 and 2006.
Strong	Medium/ High	High (unpredict.)	Cooperate (against external threat)	Cross- Licensing	In 1999 IBM and Dell signed a 7-year cross-licensing deal. Dell held only 40 patents on its direct sales business model vs. IBM's thousands on its hardware components. Dell agreed to buy parts from IBM, which was licensed to use Dell's design technology in its own PCs. The cross-licensing strategies proved complementary.
Strong	Very High	High (unpredict.)	Switch to Cooperate	Cross- Licensing	In 1979 Philips and Sony , following their "videotape format war" of the 1970s, rather than engaging in another battle, agreed to adopt the same industry standard and co-license the technology to firms willing to produce CD players.
Panel D. Asymmetric Market Power (see Online Appendix A)					
Strong	Medium/ High	Medium	Cooperate	Cross- Licensing	In 2009, GlaxoSmithKline (incumbent with market power) and Nuevolution (innovating firm) entered into a cross-licensing agreement involving technologies to efficiently identify potent drug leads. GSK obtained access to Nuevolution's lead discovery technology, and the later gained access to GSK's big pharma capability.

TABLE 2. Parameters and Values Used in the Baseline Numerical Illustration

Parameter	Definition	Parameter Value
V	Total market value of the industry	Depends on shocks
V_0	Initial market value	\$100 m
σ	Demand volatility	0.60 (base case)
u	Multiplicative factor for upward demand shock	$\exp(\sigma) \cong 1.8$
d	Multiplicative factor for downward demand shock	$1/u \cong 0.6$
V^{++}	Market value after two upward demand shocks	\$324 m
V^{+-}	Market value after one upward and one downward shock	\$108 m
V^{--}	Market value after two downward demand shocks	\$36 m
$(p, 1-p)$	Probability of (upward, downward) demand shock movement	(0.4, 0.6)
m	Market value multiplier (generic)	c or f (see below)
c	Multiplier applied to market value under cooperation	1.2
f	Multiplier applied to market value under competition (“fight”)	0.7
$(s, 1-s)$	Value-capture share of firm (T,I) for given technology strength:	Weak = (0.5,0.5) Medium = (0.6,0.4) Strong = (0.75,0.25)
I	Investment cost to commercialize technology	\$80 m
(I')	Investment cost to commercialize technology under low demand	\$40 m)
ρ	Cost of capital	20%
r	Risk-free interest rate	8%
C	Continuation value of the sleep option	See Online Appendix A
F	Licensing fee, as a percentage of V	See Online Appendix A
(F')	Licensing fee under low demand, as a percentage of V	See Online Appendix A)
W_T	Investment cost multiplier for firm T to build defensive patent wall	1.2
W'_T	Firm T’s value multiplier from building defensive patent wall	1.2
W_I	Investment cost multiplier for firm I to build defensive wall	1.3
W'_I	Firm I’s value multiplier from building defensive patent wall	2.2
b	Cost multiplier under offensive bracketing	1.3

TABLE 3. Value of Patent Strategy (Strategic NPV) in the Numerical Illustration

TECHNOLOGY STRENGTH	PATENT STRATEGY	S-NPV		
		Low σ (15%)	Base σ (60%)	High σ (90%)
Weak	COOPERATE	29	32	34
Medium	HYBRID { H Compete M/L Cooperate	24	31	32
Strong	COMPETE { H Compete M Compete L Sleep	19	29	32
	HYBRID { H Cooperate M Compete L Sleep	34	38	39
If ignore competition; invest now		20 (=NPV)		

TABLE 4. Summary of innovative firm's *ex post* choice of patent deployment mode (competition, cooperation, or coopetition) depending on the strength of technological advantage and the level of demand, under moderate (Panel A) or high (Panel B) bargaining power for the innovator.

Panel A – Base case of moderate bargaining power for innovator

	Weak technology	Medium technology	Strong technology
High demand	Competition	Competition	Competition
Medium demand	Cooperation		
Low demand		Cooperation	

Panel B – High bargaining power for innovator

	Weak technology	Medium technology	Strong technology
High demand	Coopetition	Coopetition	Coopetition
Medium demand	Cooperation	Competition	Competition
Low demand		Cooperation	

TABLE 5. Summary of *ex ante* effect of increasing the probability of tail outcomes on the expectation of switching among patent deployment modes across periods 1 and 2 depending on the demand spread, baseline demand and the strength of technological advantage, under moderate (Panel A) or high (Panel B) bargaining power for the innovator.

Panel A – Base case of moderate bargaining power for innovator

	Weak technology	Medium technology	Strong technology
High baseline demand & Low demand spread	Competition (no switching)	Competition (no switching)	Competition (no switching)
High demand spread	Increased switching between Cooperation and Competition	Increased switching between Cooperation and Competition	
Low baseline demand & Low demand spread	Cooperation (no switching)	Cooperation (no switching)	

Panel B – High bargaining power for innovator

	Weak technology	Medium technology	Strong technology
High baseline demand & Low demand spread	Coopetition (no switching)	Coopetition (no switching)	Coopetition (no switching)
High demand spread	Increased switching between Cooperation and Coopetition	See Online Appendix B, Table B5 (right column).	Increased switching between Competition and Coopetition
Low baseline demand & Low demand spread	Cooperation (no switching)	Cooperation (no switching)	Competition (no switching)

Online Appendix A

This appendix provides more detail on the following aspects of our numerical illustration: (1) it describes and derives the equilibrium outcomes under each of the nine subgames, (2) it calculates the innovator's strategic net present value (S-NPV) under the three levels of technology strength, and (3) it examines the sensitivity of the results to prior asymmetric market power favoring the incumbent.

Numerical equilibria outcomes under the nine option-game scenarios

The timeframe of our option games analysis extends over three periods. In the binomial tree set-up, market demand fluctuates stochastically in each period, with total market value (V) starting at $V_0 = \$100$ m, moving up or down by multiplicative factors $u = 1.8$ and $d = 0.6$, with a risk-adjusted (or risk-neutral) probability of an upward demand shock movement $p = 0.4$. The implied annual volatility σ ($= \ln u$) is 0.60 or 60%. The parameter u , as the multiplicative factor driving the magnitude of an upward movement in the binomial stochastic process (binomial tree) of V , is determined as $u = e^{\sigma\sqrt{t}}$, where t is the length of the time step in the binomial tree (here $t = 1$ or one period in our numerical illustration). The downward parameter d is computed as $d = 1/u$. The risk-adjusted (or risk-neutral) probability of an upward demand shock movement p is determined as $p = \frac{(1+r) - d}{u - d}$. $1 - p$ is the risk-neutral probability of a downward demand shock movement. At $t = 2$, if demand is high (after two upward shock movements) $V^{++} = 324$, if demand is medium (after one upward and one downward shock movement or vice versa) $V^{+-} = 108$, and if demand is low (after two downward shock movements) $V^{--} = 36$. After observing the realization of demand (high, medium, low) at time 2, each firm – firm T (entrant-innovator) and firm I (incumbent) – chooses its best patent deployment strategy (i.e., compete, cooperate, or wait), depending on firm T's technology strength and the state of market demand. The combination of three states of demand (high, medium, low) for each of three technology strength cases (weak, medium, strong) results in nine option-game scenarios or subgames, each potentially leading to different equilibria and optimal patent deployment strategies (Figure 1 in the main text).

The main assumptions and inputs used in the nine subgames are summarized in Figure A1, and the payoff formulas (from Figure 2 Panel B in the main text) are explained in Table A1. If the firms cooperate, the underlying total market value (V) is enlarged by a cooperation multiplier ($m = c = 1.2$) to

1.2V; if they compete aggressively, the competition multiplier is $m = f = 0.7$, resulting in reduced market value of 0.7V. Relative bargaining power shares (s for firm T, $1 - s$ for firm I) in sharing the total market value (net of all costs) or the continuation option value (C), depending on the degree of technology advantage (weak, medium, strong), are: $s=0.5$, $1-s=0.5$ (weak); $s=0.6$, $1-s=0.4$ (medium); $s=0.75$, $1-s=0.25$ (strong). Investment in technology commercialization or “entry” costs $I = \$80$ million (m). The cost of capital (ρ) is 20%, and risk-free interest (r) is 8%. The incumbent (firm I) may pay a fee as a percentage of market value (100 F percent of V , where F is between 0 and 1) to the innovator (firm T) to license its technology, according to the licensing fee schedule shown in Figure A1.

[INSERT TABLE A1 AND FIGURE A1 ABOUT HERE]

Each subgame involves two main choices on how to deploy its patent *strategically* by firm T or I: invest now or sleep (wait-and-see). Given the above assumptions, inputs (summarized in Table 2 and Figure A1) and the payoff value expressions for the various subgames (described in Figure 2 Panel A), we compute the Nash equilibrium for each subgame obtaining numerical results for the nine subgames as shown in Figure 2 Panel B. The Nash equilibrium outcome for each subgame is shown in Figure 2 Panel B as a shaded box, with the prevailing patent deployment strategy listed below it. Such numerical results correspond to the *equilibrium outcomes* in different states of demand under a compete, cooperate, or wait mode for a given degree of technological strength. Some key *equilibrium outcomes*, that are central to our analysis, are discussed next.

Three benchmark subgames (1, 3 and 5) are highlighted (in circle) and explained at more length. The other subgames are variations on these. Subgame 1 illustrates the value payoff structure of a game in which firm T uses its patent cooperatively. This game is likely to occur when firm T has a weak technology advantage. Subgame 3 represents a payoff structure when firm T uses its patent competitively. Competitive modes are prevalent in situations where firm T’s patented technology is strong. For example, under medium demand (M) where there is room for only one of the firms to operate profitably, firm T may solidify its strong technology advantage by building a defensive patent wall around its core patent

that enables it to drive the rival out.¹ If demand is high, the rival may have a fighting chance and decide to compete (e.g., identifying gaps around firm T's core patent to limit its advantage); firm T may pursue a similar strategy, resulting in a patent war. Subgame 5 presents a more complex situation where a hybrid strategy is preferable.

Subgame 1 is the simple symmetric case of weak patented technology advantage involving a cooperative mode under high demand at the end of stage I ($V^{++} = 324$) in the leftmost top matrix (subgame 1) in Figure 2 Panel B. If both firms let patents sleep (upper-left box), each firm appropriates the deferral (wait-and-see) option value according to their (equal) market power, resulting in payoffs (157, 157). If both firms invest cross-licensing their patents (lower-right box), they share the S-NPV ($mV^{++} - I = 1.2*324 - 80 = 308.8$) at $t = 2$ resulting in a (154, 154) payoff. If firm T licenses its patent to firm I for a fee F ($= 50\%$ of V^{++}) and leaves the market to its rival, firm T receives $F = 162$ and firm I receives 147 ($308.8 - 162$). The symmetric diagonal case results in payoffs (147, 162). Given these payoff outcomes, summarized in subgame 1 of Figure 2 Panel B, the resulting Nash equilibrium is *cooperation* via cross-licensing (lower-right shaded box). Each firm has a dominant strategy to invest (license), regardless of its rival's decision (for firm T, $162 > 157$ if firm I sleeps and $154 > 147$ if it invests; for firm I, $162 > 157$ if firm T sleeps and $154 > 147$ if it invests).² The Nash equilibrium is invest-invest (154, 154) with each firm licensing to the other (cross-licensing). Under weak technology advantage involving symmetric firms, both firms cooperate via cross-licensing with no incentive to deviate. Subgames 4 and 7 under medium and low demand result in similar invest-invest *cross-licensing* Nash equilibria --but with lower values for the collaborating firms, namely (25, 25) and (2, 2).

Consider now the situation involving a strong technology advantage under a *compete* mode instead, again under high demand (subgame 3). When both firm patents sleep (upper-left box), each firm appropriates the continuation value of the wait-and-see option (C) according to their (asymmetric) market

¹ If technology advantage is medium, it may not drive out the rival and cooperating strategy via licensing may be preferable at intermediate demand.

² A dominant strategy in Figure 2 Panel B is indicated by an arrow or a black dot (tip of an implied arrow) over the higher payoff choice; Nash equilibrium is reached when a pair of black dots is obtained in a cell or when the arrows point the flow to a position (box) that once reached there is no incentive to deviate from it. The resulting equilibrium is indicated by a shaded box.

power ($s = \frac{3}{4}$ for firm T and $1 - s = \frac{1}{4}$ for firm I), resulting in payoffs (98, 33).³ When both firms invest by competing (via bracketing), they share the reduced (from fighting) total market value according to their market power, with each incurring a larger cost from bracketing (by $b = 1.3$) the other's patent (e.g., NPVT = $\frac{3}{4}(0.7 \cdot 324 - 1.3 \cdot 80) = \frac{3}{4}(122.8) = 92$). This results in a (92, 31) payoff (lower-right *bracketing* box). If one firm (e.g., firm T) builds a patent wall while the rival keeps its patent sleeping (off-diagonal boxes), the former captures an enhanced share (e.g., firm T receives $s(W_T) = \frac{3}{4}(1.2)$ or 90%) of net market value ($V^{++} - I = 324 - 80 = 244$) or 220, with the rival receiving the remainder (8).⁴ This results in payoffs of (220, 8) or (68, 152) along the diagonal, depending on whether it is firm T or I that preempts the opponent. The Nash equilibrium is derived similarly (as in subgame 1), as each firm has a dominant strategy to invest regardless of the opponent's decision (for firm T, $220 > 98$ and $92 > 68$; for firm I, $152 > 33$ and $31 > 8$). The resulting equilibrium is the bottom-right, invest-invest compete via *bracketing* strategy (92, 31). Under reciprocating competition in high demand, firms feel induced to compete via patent bracketing -- even though they are better off to let their patents sleep. The fear of the rival investing in a patent wall and strengthening its position if it lets its own patent sleep puts pressure on both firms to compete aggressively, analogous to the prisoner's dilemma.

The other two cases involving a strong technology at intermediate (M) or low (L) demand levels (subgames 6 and 9) are interesting in themselves. Although they involve similar payoffs they result in different types of equilibria, with subgame 6 at medium demand resulting in an invest-sleep *patent wall* strategy (34, 0), and subgame 9 at low demand in a *sleeping* strategy by both firms with payoff (9, 0) in the top-left box. In subgame 6 involving medium demand there is room for only one firm to operate profitably so firm T can strengthen its technological advantage by investing in a protective patent wall earning monopoly profits (valued at 34) driving its rival out (0). Here, firm T has a dominant strategy to invest, regardless of its rival's decision ($34 > 9$ and $3 > -29$). Knowing that firm T is better off to compete

³ End-of-period payoff (upper-node value V^{+++}) on which continuation values are calculated is $\max(0.70V^{+++} - 1.3I, 0)$. Here competing, delayed to next period, causes market value erosion (by 30%) and investment costs are larger by $b = 1.3$ because of intense patenting around the rival's product (bracketing). The time-2 value of 98 is the average (using risk-neutral probabilities) of subsequent-period upper and lower payoffs given a competitive strategy.

⁴ Firm I receives $(1 - s)W_T V - (1 - s)W_T I$ or 10% of $324 - 30\%$ of $80 = 8$.

(invest) regardless, firm I waits (sleeps) rather than engage in a costly bracketing fight ($0 > -17$), resulting in the *patent wall* outcome (34, 0).

In subgame 9 involving low demand, it is not profitable for either firm to operate, with firm I (being at large technological disadvantage) exiting (truncating value to 0). Firm T lets its technologically-advantaged patent sleep, maintaining an option to become a monopolist should the market recover (with continuation value 9). Each firm has a dominant strategy to let its patent sleep independently of its rival's move (for firm T, $9 > -5$ and $-14 > -20$; for firm I, $0 > -1$ and $0 > -7$). Given low demand ($V^- = 36$), both firms lose value if they compete. There is just one dominant *sleeping* strategy equilibrium in the upper-left box (9, 0), with the disadvantaged firm abandoning the market and the advantaged firm having an option to be a future monopolist. In sum, when an entrant's technology is strong, aggressive competition is more likely. The precise strategy may differ across demand regimes. It may range from aggressive competition in high or medium demand, to a wait-and-see strategy (patent sleep) in low demand.

The case of medium technology under high demand in subgame 2 is noteworthy; it is similar to subgame 3, with the share of firm T being lower ($s = 60\%$ rather than $\frac{3}{4}$) assuming a bracketing war eliminates firm T's medium technology advantage, rendering the payoff outcome symmetric (61, 61). Each firm has a dominant strategy to invest, resulting in a symmetric *bracketing* equilibrium under a compete mode. However, under low (subgame 8) or medium demand (subgame 5) the firm switches to a cooperate mode, yielding different equilibrium outcomes, namely an invest-sleep *licensing* equilibrium in the lower-left box. The *hybrid* case of subgame 5 at intermediate demand is particularly interesting as investing may take the form either of a cooperative licensing strategy or of a costly bracketing competition. Firm I is better off to wait and avoid investing in a costly patent war, with firm T agreeing to cooperatively license its marginally superior (medium) patented technology to firm I for a fee (F), while still producing itself directly and capturing half the market value (a case of coopetition).

Values of Patent Deployment Strategies

As explained in the main manuscript, the values of the patent deployment strategies for innovator firm T in cases of *weak*, *medium* and *strong* technology are assessed based on the notion of S-NPV, using the following equations:

Weak Technology (Cooperative Mode):

$$\text{Strategic } NPV_0 = \frac{p^2 E_H + 2p(1-p)E_M + (1-p)^2 E_L}{(1+r)^2} = \frac{0.16(154) + 0.48(25) + 0.36(2)}{(1.08)^2} = 32 \text{ } m$$

Medium Technology (Hybrid Strategy):

$$\text{Strategic } NPV_0 = \frac{p^2 E_H + 2p(1-p)E_M + (1-p)^2 E_L}{(1+r)^2} = \frac{0.16(61) + 0.48(46) + 0.36(12)}{(1.08)^2} = 31 \text{ } m$$

Strong Technology (Competitive Mode):

$$\text{Strategic } NPV_0 = \frac{p^2 E_H + 2p(1-p)E_M + (1-p)^2 E_L}{(1+r)^2} = \frac{0.16(92) + 0.48(34) + 0.36(9)}{(1.08)^2} = 29 \text{ } m$$

Patent option portfolios for firm T are then valued by comparing such S-NPVs (summarized in Table 3) to the static NPV.

Asymmetric Prior Market Power

We next consider how our main numerical results change under the asymmetric situation when incumbent firm I has larger *prior* market power and examine how an *ex ante* asymmetric power distribution here affects the interplay between competition and cooperation (for a case of cooperative cross-licensing despite their initial power asymmetry, see the example of GlaxoSmithKline and Nuevolution in Table 1). Suppose *a priori* incumbent firm I has a 75% market share dominance. If innovative firm T's new technology is medium (marginally superior), the initial asymmetry in favor of incumbent firm I will be reduced only partly (shares will adjust to $s = 40\%$ for firm A and $1 - s = 60\%$ for B). Suppose the incumbent's initial market power advantage is eliminated, however, if firm T's technology is strong, reverting back to an *ex post* symmetric situation (50-50). Suppose further the relative market shares for firms T and I in the power asymmetry case (under weak, medium or strong technology advantage by firm T) are, respectively: 0.25 and 0.75 (weak); 0.4 and 0.6 (medium); 0.5 and 0.5 (strong). In Figure A2, the four circles provide examples of subgames that shift between compete and cooperate modes and vice versa in this asymmetry case, compared to the previous symmetric base case in the main text. Previous symmetry games that under weak technology were earlier characterized by cooperation, now change into competition due to asymmetry resulting from incumbent firm I's prior market power; similarly, the subgame involving medium technology under low demand previously characterized by cooperation now turns into a compete mode. By contrast, the previous asymmetry due to innovative firm

T's strong technological advantage that previously led to a compete mode is now offset by the incumbent's prior power advantage so the resulting relative symmetry now supports a cooperate mode. That is, cases that were previously symmetric, resulting in cooperation, now become asymmetric switching to competition, and vice versa. What matters, therefore, is the *relative* overall competitive advantage (or players' asymmetry), not just the absolute technology strength of the innovator. Figure A3 shows the revised outcomes and resulting option game equilibria in the circled subgames.

[INSERT FIGURES A2 AND A3 ABOUT HERE]

TABLE A1. Explanation of Payoff Formulas for Numerical Illustration

Patent Deployment Strategy	Subgame #	Payoff Formulas	Input Parameters	Explanation
Cross-Licensing	#1,4,7	Firm T: $s(mV - I)$ Firm I: $(1 - s)(mV - I)$	$s, 1 - s$: sharing terms based on relative market power associated with the degree of firm T's technology strength V : market value $m = c$: exercise mode multiple = cooperation I : investment cost of commercialization I' : investment cost of commercialization under low demand	(# 1,4,7,8) When both firms cooperate via cross-licensing each other's patents, they share equally ($\frac{1}{2}$) the enlarged net market value, i.e., $s(mV - I) = \frac{1}{2}(1.2V - I)$.
	- or - #8	- or - Firm T: $s(mV - I')$ Firm I: $(1 - s)(mV - I')$		
Licensing	#1,4	Firm T: FV Firm I: $(mV - I) - FV$ or Firm I: FV Firm T: $(mV - I) - FV$	V : market value F : licensing fee, as percentage of V F' : licensing fee under low demand, as a percentage of V . $m = c$: exercise mode multiple = cooperation I : investment cost of commercialization I' : investment cost of commercialization under low demand $s, 1 - s$: sharing terms based on relative market power associated with the degree of firm T's technology $C^* = \max(mV - I' - I, 0)$: continuation value of a wait-and-see (call) option $C^{*'} = \max(mV - I' - I', 0)$: continuation value of a wait-and-see (call) option to become a monopolist where $m = 1$ (monopoly)	(# 1,4) One firm (T or I) licenses its patented technology to the other for a fee agreeing to stay out of the market; the other keeps its own patent sleeping and uses the licensed technology to capture the whole market value net of the paid fee. - or - (# 7) Under low demand in case of weak technology, the firm (T or I) that licenses the technology from the other (in exchange for a fee) waits-and-sees rather than operate (net market value is replaced by option value). - or - (# 8) When T licenses its moderately superior technology to I (while I lets its own patent sleep), T's small advantage is eliminated in exchange for receiving a licensing fee, with T receiving half ($s = \frac{1}{2}$) the continuation value (due to low demand) plus the fee and I paying the fee in exchange for receiving half ($1 - s = \frac{1}{2}$) the continuation value. T pays a different fee (F') to license I's technology and get $C^{*'} (provided I stays out of the market so T has an option on the whole market value as a potential future monopolist).$ - or - (# 5) T licenses out its marginally superior technology to I and still operates in the market, receiving half ($s = \frac{1}{2}$) the enlarged net market value plus the licensing fee, while I pays the fee with the right to operate later receiving half ($1 - s = \frac{1}{2}$) the continuation value.
	- or - #7	- or - Firm T: FV Firm I: $C^* - FV$ or Firm T: $C^* - FV$ Firm I: FV		
	- or - #8	- or - Firm T: $sC^* + FV$ Firm I: $(1 - s)C^* - FV$ or Firm T: $C^{*'} - F'V$ Firm I: $F'V$		
	- or - #5	- or - Firm T: $s(mV - I) + FV$ Firm I: $(1 - s)C^* - FV$		

Table A1 is continued on the next page.

Sleeping	#2,3,5,6	Firm T: $s C$ Firm I: $(1 - s) C$	$s, 1 - s$: sharing terms based on relative market power associated with the degree of firm T's technology strength I : investment cost of commercialization I' : investment cost of commercialization under low demand $C = \max(m V^{++} - I, 0)$: continuation value of a wait-and-see (call) option* $C^* = \max(m V^{--} - I, 0)$: continuation value of a wait-and-see (call) option $C^{**} = \max(m V^{++} - I', 0)$: continuation value of a wait-and-see (call) option to become a monopolist where $m = 1$ (monopoly)	(# 2,3,5,6) When both firms sleep, they postpone their decision to compete to the next stage (time period 3), with T that has a strong technology advantage capturing most of the continuation value (C) according to its market power ($s = \frac{3}{4}$), while I gets $\frac{1}{4}C$. - or - (# 8) When both firms let their patented technology sleep under low demand in case of medium technology, they share the continuation value of the option (C^*) to postpone their decision to cooperate the next stage (time period 3), where C^* is based on a lower strategy implementation (investment) cost due to low demand. - or - (# 9) Under low demand in case of strong technology, T receives a full exclusive option to be a future monopolist (receiving C^{**}) while I abandons the market (receiving 0) due to the low demand and its serious technology disadvantage.
	- or -	- or -		
	#8	Firm T: $s C^*$ Firm I: $(1 - s) C^*$		
Bracketing	- or -	- or -		
	#9	Firm T: C^{**} Firm I: 0		
Bracketing	#2,3,6,9	Firm T: $s(m V - b I)$ Firm I: $(1 - s)(m V - b I)$	$s, 1 - s$: sharing terms based on relative market power associated with the degree of firm T's technology strength V : market value $m = f$: exercise mode multiple = competition ("fight") I : investment cost of commercialization b : bracketing cost multiplier $C^{**} = \max(V^{++} - b I, 0)$: continuation value of a wait-and-see (call) option	(# 2,3,6,9) When both firms compete aggressively via patent bracketing, they both share a reduced market value based on their respective market power ($s = \frac{3}{4}$ vs. $1 - s = \frac{1}{4}$) and incur higher costs due to bracketing ($b I = 1.3 I$), i.e., T receives $s(m V - b I) = \frac{3}{4}(0.7 V - 1.3 I)$ and I gets $\frac{1}{4}(0.7 V - 1.3 I)$. - or - (# 5) I competes by bracketing while T lets its patent sleep. Assuming I operates now and T later, firms I and T share the adjusted NPV value (given the higher bracketing costs, $b I$) and the continuation value C^{**} (on $\max(V - b I, 0)$) according to their relative market power ($s = 0.4$ and $1 - s = 0.6$).
	- or -	- or -		
	#5	Firm T: $s C^{**}$ Firm I: $(1 - s)(V - b I)$		

Table A1 is continued on the next page.

* C is calculated as the expectation (using risk-neutral probabilities, p) over the end-of-stage II (time period 3) payoffs given a cooperative patent strategy discounted back by one year at the risk-free rate (r):

$$C = \frac{p[\max(mV^{+++} - I, 0)] + (1 - p)[\max(mV^{++-} - I, 0)]}{(1 + r)} \quad \text{where} \quad \frac{pmV^{+++} + (1 - p)mV^{++-}}{(1 + r)} = mV^{++} \quad (\text{time period 2 payoff}).$$

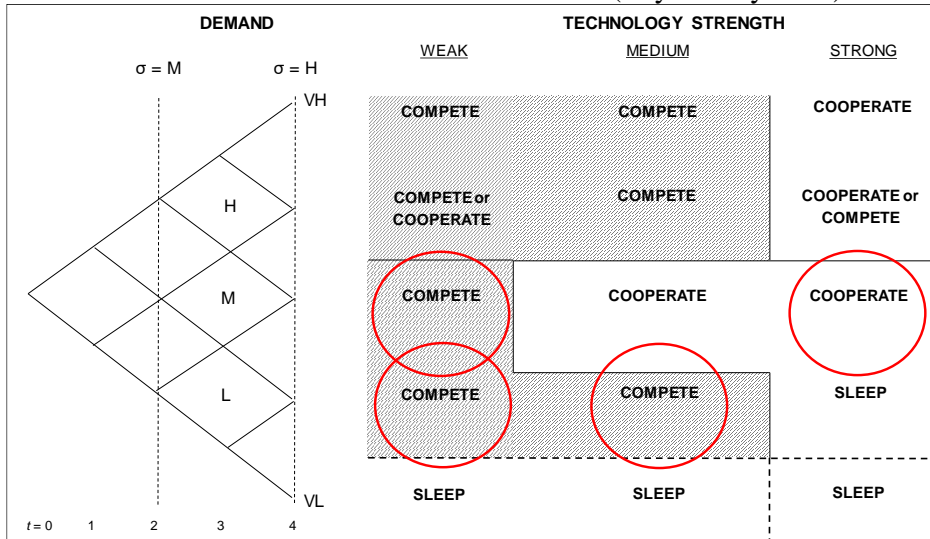
Patent Wall [†]	#2,3,6,9	Firm T: $s W_T (V - I)$ Firm I: $(1 - s W_T) V - (1 - s W_T) I$	$s, 1 - s$: sharing terms based on relative market power associated with the degree of firm T's technology strength V : market value pie W_T : patent wall cost multiplier for firm T W'_T : patent wall value multiplier for firm T $W_T = W'_T$: for firm T W_I : patent wall cost multiplier for firm I W'_I : patent wall value multiplier for firm I $C = \max(m V^{++} - I, 0)$: continuation value of a wait-and-see (call) option	(# 2,3,6,9) when one firm (T or I) competes pursuing a patent wall strategy (paying a cost premium of 20% or 30% to fortify its position via building a patent wall around its core patented technology) while the other waits keeping its patent sleeping, both firms stay in the game sharing total value based on their market power, i.e., with T receiving $s W_T (V - I)$ and I receiving the remainder.
	- or -	- or -		- or -
	#3,6,9	Firm T: $[1 - (1 - s) W'_I] V - s W_I I$ Firm I: $(1 - s) (W'_I V - W_I I)$		(# 3,6,9) A more general situation applies to these games (high demand, strong technology). When pursuing a patent wall strategy, I receives $(1 - s) (W'_I V - W_I I)$ with W_I being the patent wall cost amplifier (or multiplier) and W'_I the patent wall value enhancer (or multiplier), with T receiving the remainder.
	- or -	- or -		- or -
	#2	Firm T: $s' C$ Firm I: $(1 - s') W_I (V - I)$		(# 2) When pursuing a patent wall strategy under medium demand in case of medium technology, I receives a share $(1 - s')$ of enhanced market value and T receives a share (s') of future continuation value while it sleeps ($s' C$). Actual market shares of T and I are reversed with that of the latter $(1 - s')$ being amplified due to the raising of a defensive wall.

[†] Under medium and low demand in case of strong technology, firm T pursues a patent wall strategy while firm I keeps its patent sleeping. As the level of market demand only allows for one firm to survive, firm T becomes a monopolist ($s = 1$) and firm I gets 0. Under high demand in case of medium technology, when firm T raises a patent wall around a less advantaged technology (relative to firm I's one), the former obtains the full monopoly value (V) which is not enhanced by W'_T due to a lower technology gap among the two rivals.

FIGURE A1. Summary of Main Assumptions and Input Parameters

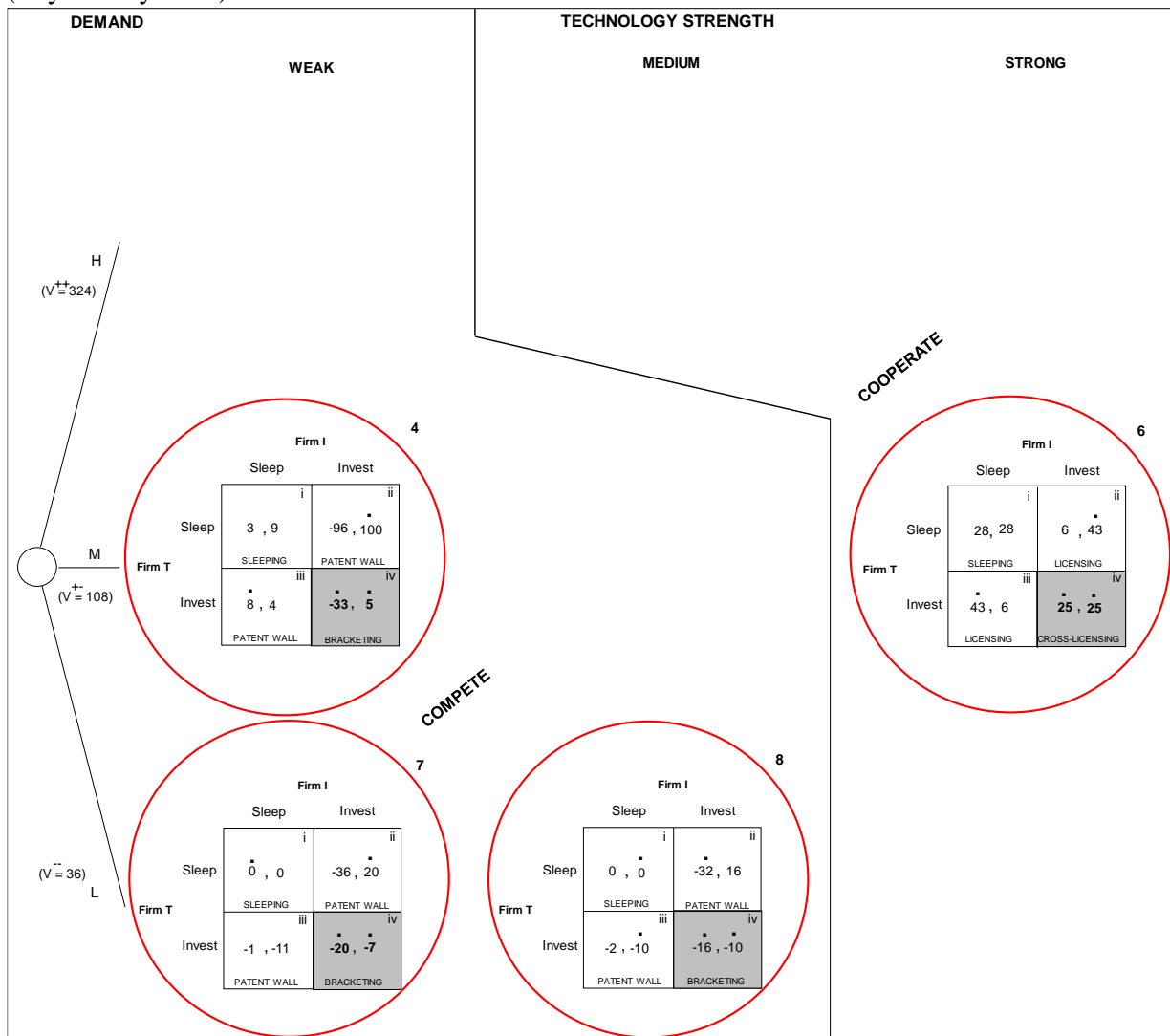
Exercise mode multiple (m)		Market power share (s)			
Cooperation (c)	1.2	FIRMS			
Competition/Fight (f)	0.7	Symmetric		Asymmetric	
		TECHNOLOGY STRENGTH		T	I
		Weak	50%	50%	25% 75%
		Medium	60%	40%	40% 60%
		Strong	75%	25%	50% 50%
Patent Wall multiplier (W)		Bracketing Cost multiplier (b)			
		FIRM			
		T	I	T	I
Cost Multiplier (W/I)				1.3	1.3
W/T		1.2			
W/I				1.3	
Value Multiplier ($W' V$)					
$W'T$		1.2			
$W'I$				2.2	
Licensing Fee (F)		TECHNOLOGY STRENGTH			
		Weak	Medium	Strong	
HIGH DEMAND (H)		50%			
MEDIUM/LOW DEMAND (M/L)		40%			
MEDIUM DEMAND (M)		20%			
LOW DEMAND (L)				15%	
Other valuation inputs					
Investment cost (I): \$ 80 million					
Base volatility (σ): 60%					
Cost of capital (p): 20%					
Riskless interest rate (r): 8%					

FIGURE A2. Changes in Competitive vs. Cooperative Strategy Modes in the Numerical Illustration when Incumbent Firm I Has More Prior Market Power (Asymmetry Case)



Note: Circles indicate subgames that shift between competitive and cooperative modes when market power becomes asymmetric.

FIGURE A3. Revised Subgame Outcomes and Equilibria when Incumbent Firm I Has More Market Power (Asymmetry Case)



Online Appendix B

In our extended analysis, we consider a market for an undifferentiated product where incumbent firm I has monopolized the market up to the current time, $t = 0$. The market continues over two more time periods, designated as $t \in \{1, 2\}$. Periods 0, 1, and 2 may each represent different amounts of calendar time. The inverse market demand function at time t is $P_t = \theta_t - Q_t$, where P_t is the market price per unit, Q_t is the total industry output of all firms producing at time t , and $\theta_t \equiv \lambda + X_t$ is the demand intercept, with λ being baseline demand and X_t being a period-specific demand shock. This shock allows demand to increase, decrease, or stay the same between periods 1 and 2, with X_1 assumed to equal zero, and X_2 following a trinomial distribution that can take the value $+\sigma$ or $-\sigma$ with probability of $\gamma/2$ each, and can take the value zero with probability $1 - \gamma$, where $\sigma > 0$ and $0 < \gamma \leq 1$. We use this trinomial form since it is the simplest and most tractable probability distribution that allows switches among all three market structures (competition, cooperation, and coopetition) while also controlling the probability of extreme outcomes (tails). The demand shock X_2 has mean 0 and variance $\gamma\sigma^2$. We refer to γ as the tail probability parameter as it determines the probability of demand outcomes in the tails, and to σ as the demand spread or volatility as it determines the spread or range of possible demand outcomes. One advantage of using the trinomial distribution is that it allows us to decompose overall demand volatility ($\gamma\sigma^2$) into two components: how spread out the extreme values are (σ) and how likely they are to occur (γ).

The incumbent firm I can produce output using existing technology at a constant marginal cost per unit ϕ , which we refer to as the baseline marginal cost, with $0 \leq \phi < \lambda$. For convenience, we also refer to the difference between baseline demand and baseline marginal cost, $\lambda - \phi$, as the baseline margin. However, because we hold the baseline marginal cost ϕ constant throughout our analysis, changes in baseline demand and changes in baseline margin are essentially identical, so we will sometimes refer to these changes interchangeably. In period 0, technological innovator firm T develops and patents a process innovation that lowers the marginal cost of production below the baseline level ϕ by an amount $\beta > 0$, reducing marginal production cost to $\phi - \beta > 0$. We refer to β as the strength of the technological advantage, where $\beta < \lambda - \phi$ to ensure positive margin for firm I. Initially, in period 0, firm T has no assets-in-place other than this patent, so the value of the firm and the value of the patent are *ex ante* equivalent.

In each subsequent period ($t = 1$ or 2), there are three ways firm T can exercise this patent: (1) It can pay a fixed capital cost of $\kappa > 0$ to obtain the commercialization capability to produce and sell output during that period at the lower marginal cost $\phi - \beta$, engaging in asymmetric Cournot competition with incumbent firm I (which is producing at the higher marginal cost ϕ). We call this the “competition” deployment mode, as it involves innovator firm T exploiting its technological advantage for proprietary or exclusionary benefit by competing against firm I, and we abbreviate it as P for “produce.” (2) It can exercise its patent rights in a non-exclusionary fashion licensing its superior technology to the incumbent in a “gain sharing” licensing deal. Such a license deal would share the technology benefits with the incumbent by allowing firm I to also reduce its marginal cost to $\phi - \beta$, in exchange for paying innovator firm T a licensing fee consisting of a share α of the incumbent’s incremental profit gain from using the licensed technology (relative to the profit it would have earned without the technology), where $0 < \alpha < 1$. We call this arrangement, in which the innovator does not produce output to compete against firm I but rather lets the incumbent retain its monopoly, a “cooperation” deployment mode, and abbreviate it as L for “license” only. (3) In a hybrid arrangement, firm T can both produce and license concurrently, thereby engaging in symmetric Cournot competition with the incumbent where both firms enjoy the same lower marginal cost from the new technology of $\phi - \beta$, while also receiving a gain-sharing licensing fee from the incumbent. We call this the “coopetition” deployment mode, and abbreviate it as B for “both” producing and licensing concurrently. In principle, innovator firm T could choose neither to produce nor license, but under our assumptions this choice is strictly dominated by licensing, so we ignore this possibility.

Whereas innovator firm T chooses whether to produce output in periods 1 and/or 2, we assume here for simplicity that the incumbent remains in the market for both periods. To guarantee that the incumbent remains in the market for periods 1 and 2, we assume $\phi < \lambda - \sigma - \beta$, so that base demand is high enough to enable the incumbent earn a profit under the worst-case demand scenario (where X_t is $-\sigma$) regardless of the realized value of the demand shock and firm T’s choice of patent deployment mode. This assumption ensures that the incumbent will survive the two period demand shocks assuming the incumbent’s fixed costs are sunk. Alternatively, one might instead assume the incumbent’s longstanding commitments create exit barriers that ensure it remains in the market for both remaining periods.

Derivation of *ex post* mathematical conditions

Based on the aforementioned details and the assumptions provided in the main manuscript, the *ex post* profit functions for each firm under the three patent deployment (exercise) modes are shown in Table B1. Based on these *ex post* profit functions, Table B2 shows the *ex post* conditions under which each of the three patent exercise modes is chosen by a profit-maximizing firm T. These conditions are derived by applying algebra to firm T's profit functions under the three exercise modes (P, L, and B), which are shown as $\Pi_{T,P,t}$, $\Pi_{T,L,t}$, and $\Pi_{T,B,t}$ in Table 1 from the main text. Specifically, the first row of Table B2 identifies the conditions under which firm T chooses the Competition deployment mode of producing without licensing (P), which occurs when $\Pi_{T,P,t} > \max \{\Pi_{T,L,t}, \Pi_{T,B,t}\}$. Likewise, the second row in Table B2 identifies the conditions under which firm T chooses the Cooperation deployment mode of licensing without producing (L), which occurs when $\Pi_{T,L,t} > \max \{\Pi_{T,P,t}, \Pi_{T,B,t}\}$. Similarly, the third row of Table B2 identifies the conditions under which firm T chooses the Coopetition deployment mode of both producing and licensing (B), which occurs when $\Pi_{T,B,t} > \max \{\Pi_{T,P,t}, \Pi_{T,L,t}\}$. Table 5 in the main text is simply a graphical representation of the algebraic conditions shown here in Table B2. For the first period ($t = 1$), the conditions required for each deployment mode are deterministic, and can be seen by simply substituting $X_1 = 0$ into Table B2. Mathematica code detailing the derivation of the conditions in Table B2 is available upon request.

[INSERT TABLES B1 AND B2 ABOUT HERE]

Derivation of *ex ante* mathematical conditions

Because there are three patent deployment modes (P, L, and B), there are six possible ways for firm T to switch its deployment mode between periods – Competition to Cooperation (P to L), Competition to Coopetition (P to B), Cooperation to Competition (L to P), Cooperation to Coopetition (L to B), Coopetition to Competition (B to P), and Coopetition to Cooperation (B to L). Table B3 shows the *ex ante* conditions under which each of these six types of switches may take place with a probability of $\gamma/2$. These conditions are derived by applying algebra to firm T's profit functions under the three deployment modes across the two time periods. For example, the first row in Table B3 shows the *ex ante* conditions under which firm T has a probability $\gamma/2$ of switching from Competition to Cooperation (P to

L), which occurs when $\Pi_{T,P,1} > \max\{\Pi_{T,L,1}, \Pi_{T,B,1}\}$ and $Prob[\Pi_{T,L,2} > \max\{\Pi_{T,P,2}, \Pi_{T,B,2}\}] = \gamma/2$. Likewise, the second row shows the conditions where switching from Competition to Coopetition (P to B) occurs with probability $\gamma/2$, so that $\Pi_{T,P,1} > \max\{\Pi_{T,L,1}, \Pi_{T,B,1}\}$ and $Prob[\Pi_{T,B,2} > \max\{\Pi_{T,P,2}, \Pi_{T,L,2}\}] = \gamma/2$. Similarly, the third row shows conditions required for switching from Cooperation to Competition with probability $\gamma/2$, so that $\Pi_{T,L,1} > \max\{\Pi_{T,P,1}, \Pi_{T,B,1}\}$ and $Prob[\Pi_{T,P,2} > \max\{\Pi_{T,L,2}, \Pi_{T,B,2}\}] = \gamma/2$. And so on for the last three rows of Table B3. Mathematica code detailing the derivation of the conditions in Table B3 is available upon request.

[INSERT TABLE B3 ABOUT HERE]

Tables 3 and 4 in the main text are simply graphical representations of the algebraic conditions shown here in Table B3. However, Tables 3 and 4 in the main text are condensed, in the sense that switches in opposite directions – for example, P to L switches and L to P switches – are shown as a single cell in those tables. We used this condensed format in the main text to make those tables easier to follow. In this Online Appendix, for the sake of completeness and transparency, we present the full uncondensed versions of those tables as Tables B4 and B5 (corresponding, respectively, to Tables 3 and 4 in the text).

[INSERT TABLES B4 AND B5 ABOUT HERE]

Footnote 7 in the text notes that, to be subject to two different types of possible switches at the same time, the innovator must have started in the competition region for period 1, because in order to move straight up into the brown region of Figure 7 Panel B, we must start in the yellow region. That is, there is no way to get into the brown region by moving straight up from the blue or red regions. This is necessary but not sufficient, since it is impossible to reach the brown region by moving straight upward from the far-right side of the yellow region, where the technological advantage is sufficiently high. If the innovator starts with cooperation in period 1 (red), then it can only switch to coopetition (purple), but not to competition, in period 2. Likewise, if the innovator starts with coopetition in period 1 (blue), then under most conditions the only possible switch is into cooperation (purple), but there is a narrow set of conditions (the left half of the small green triangle) where it can switch to competition. Of course, anything might happen if other parameters, like technological advantage β , change between periods, but here we focus on what happens when only σ changes between periods, *ceteris paribus*.

TABLE B1. *Ex post* profit functions in the formal model for incumbent firm I and technological innovator firm T under the three patent deployment modes of competition, cooperation, and coopetition.

Mode	Incumbent firm I	Technological innovator firm T
Competition: T produces without licensing (P)	$\Pi_{I,P,t} = \left(\frac{\theta_t - \phi - \beta}{3}\right)^2$	$\Pi_{T,P,t} = \left(\frac{\theta_t - \phi + 2\beta}{3}\right)^2 - \kappa$
Cooperation: T licenses without producing (L)	$\Pi_{I,L,t} = \left(\frac{\theta_t - \phi + \beta}{2}\right)^2 - \frac{\alpha\beta}{2}\left(\theta_t - \phi + \frac{\beta}{2}\right)$	$\Pi_{T,L,t} = \frac{\alpha\beta}{2}\left(\theta_t - \phi + \frac{\beta}{2}\right)$
Coopetition: T both produces and licenses (B)	$\Pi_{I,B,t} = \left(\frac{\theta_t - \phi + \beta}{3}\right)^2 - \frac{4\alpha\beta}{9}(\theta_t - \phi)$	$\Pi_{T,B,t} = \left(\frac{\theta_t - \phi + \beta}{3}\right)^2 + \frac{4\alpha\beta}{9}(\theta_t - \phi) - \kappa$

Note: $\theta_t \equiv \lambda + X_t$ is the demand intercept, with λ being baseline demand and X_t being a period-specific demand shock. β is the strength of the innovator's technological cost advantage (cost savings), ϕ is the marginal cost of the existing technology used by the incumbent, κ is capital cost per period required to produce output, and α is the innovator's bargaining power expressed as a fraction of the licensee's gains paid to the innovator.

TABLE B2. Firm T's *ex post* profit-maximizing choice of patent deployment mode, as a function of actual demand shock value and other parameters

Patent exercise mode	Conditions under which that deployment mode will be chosen by firm T
Competition: Firm T produces without licensing (P)	$\left(\alpha \leq \frac{1}{2} \text{ and } \beta^2 \geq \frac{16\kappa}{3\alpha(4-3\alpha)}\right) \text{ or } \left(\alpha \leq \frac{1}{2} \text{ and } X_t \geq \phi - \lambda - 2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)}\right) \text{ or}$ $\left(\beta^2 \geq \frac{16\kappa}{3\alpha(4-3\alpha)} \text{ and } X_t < \phi - \lambda + \frac{3\beta}{4\alpha-2}\right) \text{ or } \left(\phi - \lambda - 2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)} \leq X_t < \phi - \lambda + \frac{3\beta}{4\alpha-2}\right)$
Cooperation: Firm T licenses without producing (L)	$\left(\alpha \leq \frac{1}{2} \text{ and } \beta^2 < \frac{16\kappa}{3\alpha(4-3\alpha)} \text{ and } X_t < \phi - \lambda - 2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)}\right) \text{ or}$ $\left(\alpha > \frac{1}{2} \text{ and } \beta^2 < \frac{36\kappa(2\alpha-1)^2}{1+2\alpha+46\alpha^2-36\alpha^3} \text{ and } \theta - \lambda + \frac{3\beta}{4\alpha-2} \leq X_t < \phi - \lambda - \beta + \frac{\alpha\beta}{4} + \frac{1}{4}\sqrt{144\kappa + \alpha\beta^2(28+\alpha)}\right) \text{ or}$ $\left(\beta^2 < \frac{16\kappa}{3\alpha(4-3\alpha)} \text{ and } X_t < \phi - \lambda + \min\left\{\frac{3\beta}{4\alpha-2}, -2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)}, -\beta + \frac{\alpha\beta}{4} + \frac{1}{4}\sqrt{144\kappa + \alpha\beta^2(28+\alpha)}\right\}\right) \text{ or}$ $\left(\beta^2 < \frac{36\kappa(2\alpha-1)^2}{1+2\alpha+46\alpha^2-36\alpha^3} \text{ and } X_t < \phi - \lambda + \min\left\{-2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)}, -\beta + \frac{\alpha\beta}{4} + \frac{1}{4}\sqrt{144\kappa + \alpha\beta^2(28+\alpha)}\right\}\right) \text{ or}$ $\left(\frac{36\kappa(2\alpha-1)^2}{1+2\alpha+46\alpha^2-36\alpha^3} \leq \beta^2 < \frac{16\kappa}{3\alpha(4-3\alpha)} \text{ and } X_t < \phi - \lambda + \min\left\{\frac{3\beta}{4\alpha-2}, -2\beta + \frac{9\alpha\beta}{4} + \frac{3}{4}\sqrt{16\kappa - 3\alpha\beta^2(4-3\alpha)}\right\}\right)$
Coopetition: Firm T both produces and licenses (B)	$\left(\alpha > \frac{1}{2} \text{ and } \beta^2 \geq \frac{36\kappa(2\alpha-1)^2}{1+2\alpha+46\alpha^2-36\alpha^3} \text{ and } X_t \geq \phi - \lambda + \frac{3\beta}{4\alpha-2}\right) \text{ or}$ $\left(\alpha > \frac{1}{2} \text{ and } \beta^2 < \frac{36\kappa(2\alpha-1)^2}{1+2\alpha+46\alpha^2-36\alpha^3} \text{ and } X_t \geq \phi - \lambda - \beta + \frac{\alpha\beta}{4} + \frac{1}{4}\sqrt{144\kappa + \alpha\beta^2(28+\alpha)}\right)$

TABLE B4. Summary of *ex ante* impact of increasing the tail probability (γ) on the expectation (probability) of switching patent deployment modes between periods 1 and 2 under moderate (top panel) or high (lower panel) bargaining power (α) for different technology strengths (β)

		Weak technology (β)	Medium technology (β)	Strong technology (β)
Moderate bargaining power (α)	High baseline demand (λ) & Low demand spread (σ)	Competition (no switching)	Competition (no switching)	Competition (no switching)
	High baseline demand (λ) & High demand spread (σ)	Increased switching from Competition to Cooperation	Increased switching from Competition to Cooperation	Competition (no switching)
	Low baseline demand (λ) & High demand spread (σ)	Increased switching from Cooperation to Competition	Increased switching from Cooperation to Competition	Competition (no switching)
	Low baseline demand (λ) & Low demand spread (σ)	Cooperation (no switching)	Cooperation (no switching)	Competition (no switching)
High bargaining power (α)	High baseline demand (λ) & Low demand spread (σ)	Coopetition (no switching)	Coopetition (no switching)	Coopetition (no switching)
	High baseline demand (λ) & High demand spread (σ)	Increased switching from Coopetition to Cooperation	See Table B5 for details.	Increased switching from Coopetition to Competition
	Low baseline demand (λ) & High demand spread (σ)	Increased switching from Cooperation to Coopetition		Increased switching from Competition to Coopetition
	Low baseline demand (λ) & Low demand spread (σ)	Cooperation (no switching)	Cooperation (no switching)	Competition (no switching)

TABLE B5. Summary of *ex ante* impact of increasing tail probability (γ) on the expectation of switching patent deployment modes between periods 1 and 2 under high bargaining power (α) and medium technology (β)

		Medium technology (β)	
		Low demand spread (σ)	High demand spread (σ)
High bargaining power (α)	Very high baseline demand (λ)	Coopetition (no switching)	Coopetition (no switching)
	High baseline demand (λ)	Increased switching from Coopetition to Competition	Increased switching from Coopetition to Competition
	Medium/high baseline demand (λ)	Increased switching from Competition to Coopetition	Increased switching from Coopetition to Cooperation
	Medium baseline demand (λ)	Competition (no switching)	Increased switching from Competition to both Cooperation and Coopetition
	Medium/low baseline demand (λ)	Increased switching from Competition to Cooperation	Increased switching from Cooperation to Coopetition
	Low baseline demand (λ)	Increased switching from Cooperation to Competition	Increased switching from Cooperation to Competition
	Very low baseline demand (λ)	Cooperation (no switching)	Cooperation (no switching)