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PATENT THICKETS, JUDICIAL ENFORCEMENT AND THE MARKET FOR INNOVATION: THEORY AND EVIDENCE FROM PATENT LITIGATION

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ABSTRACT

Patent Thickets, Judicial Enforcement and the Market for Innovation: Theory and Evidence from Patent Litigation

We study how fragmentation of patent rights ('patent thickets') and the formation of the Court of Appeal for the Federal Circuit (CAFC) affected the duration of patent disputes, and thus the speed of technology diffusion through licensing. We develop a model of patent litigation which predicts faster settlement agreements when patent rights are fragmented and when there is less uncertainty about court outcomes, as was associated with the 'pro-patent shift' of CAFC. The model also predicts that the impact of fragmentation on settlement duration should be smaller under CAFC. We confirm these predictions empirically using a dataset that covers nearly all patent suits in U.S. federal district courts during the period 1975-2000. Finally, we analyze how fragmentation affects total settlement delay, taking into account both reduction in duration per dispute and the increase in the number of required patent negotiations associated with patent thickets.

JEL Classification: K41, L24, O31 and O34
Keywords: anti-commons, Court of Appeals for the Federal Circuit, litigation, patent thickets, patents and settlement

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1 Introduction

The licensing and sale of patents - the 'market for innovation' - are an important source of R&D incentives. Recent research has shown that transactions in patent rights contribute to the diffusion of technology, and strongly affect the incentives for firms to undertake innovation in the first place (Arora, Fosfuri and Gambardella, 2001). Firms increasingly recognize and exploit the commercial potential of their patent portfolios through licensing. To cite one high profile example, IBM reports earning 958 million from its portfolio.[1] But the market for innovation is not just important for large firms. For small firms patents are often their most important asset, and the ability to license or sell them effectively is critical to preserving their innovation incentives and access to venture capital finance (Baum and Silverman, 2004). Moreover, transactions in patent rights are important to the development of efficient market structures in high technology sectors. In biotechnology and other high technology areas, transactions in patent rights strongly shape the division of labor, and nature of competition, between small firms who specialize in radical innovation and larger firms whose comparative advantage is in the development, production and marketing of these innovations (Gans, Hsu and Stern, 2002).

One of the difficulties in studying transactions in patent rights is the lack of large scale data sets. As a result, existing studies are typically based on survey information. The only exception of which we are aware is Serrano (2009), who exploits patent office information on changes in the registered ownership to study the sale of patents.

In this paper we study the market for innovation through a new lens – the settlement of patent infringement disputes. It is common for patents to be licensed as part of settlement agreements that arise from patent disputes (Anand and Khanna, 2000). An effective market for innovation requires that such disputes are settled as quickly as possible. Delay and uncertainty in the settlement and licensing process mean slower diffusion of patented technology. Moreover, longer delays would typically be associated with higher transaction costs for the negotiating parties.[2] We use comprehensive data on the timing of settlements in patent disputes filed

[1] The figure was obtained from IBM's 2007 annual report and refers to the category listed as 'IP and custom development' income.

[2] The focus of our paper is on *ex post* negotiations where delay reduces the surplus that the negotiating parties will share, and thus reduces welfare. In more general settings, however, faster resolution of disputes may

in U.S. courts to study this issue. As a window on the market for innovation, studying the duration of patent disputes has both advantages and limitations. First, the speed with which disputes are resolved is itself important for innovation, and an indication of how well the market for innovation works. The second advantage is that we have much more extensive data on patent settlements than on licensing. In particular, this paper exploits information on essentially all patent cases filed in U.S. courts over the period 1978-2000. The main limitation of our empirical strategy is that we do not observe the terms of patent settlements, and thus do not know whether licensing actually occurred as part of the agreement (or court order).

Licensing negotiations are shaped both by the characteristics of the patents and disputants, and by the legal environment within which negotiations take place. Two key aspects of the environment have attracted attention from economists, legal scholars and policy-makers – the fragmentation of patent rights ('patent thickets') and the establishment of the centralized appellate court for patents (CAFC) in 1982. Scholars have claimed that the interplay of fragmentation and the more predictable and pro-patent regime under CAFC has increased the complexity of the bargaining framework and created impediments for innovation (Heller and Eisenberg, 1998; Eisenberg, 2001; Jaffe and Lerner, 2004). The argument is that greater ownership fragmentation generates higher transaction costs, longer bargaining delays and higher risk of bargaining failures. Despite the appeal of this argument, the evidence is not particularly supportive. Surveys from the biomedical industry indicate relatively few cases of substantial bargaining delays or failures in connection with licensing of research tools and material transfer agreements (Walsh, Arora and Cohen, 2004).

Recently, Lichtman (2006) challenged the anti-commons view, arguing that the proliferation of overlapping patent rights can actually facilitate negotiations and speed up technology diffusion. The idea is that when an innovator needs to secure the use of a variety of patented inputs which are owned by distinct patentees, the value at stake in each negotiation is lower so each of the potential licensors has a smaller incentive to litigate. If this happens, owner-

not be welfare-enhancing. Two examples illustrate the point. First, a final court decision can generate welfare gains by removing an 'unworthy' patent or by clarifying for future innovators that the patent is valid. Second, liquidity constraints may force a disputant to settle early but on more unfavourable terms than would otherwise occur. Since the division of rents between innovators affects their relative incentives to invest, this is not just a distributional issue but can actually affect welfare.

ship fragmentation can speed up settlement of patent disputes, promoting rather than retarding technology diffusion and the market for innovation. Of course, even if fragmentation did reduce settlement delay per dispute, the sheer numbers of patents (required negotiations) associated with patent thickets could still cause total settlement delay to rise.

In this paper we investigate how the fragmentation of patent rights and the establishment of CAFC in 1982 affected the length of patent infringement disputes. We develop a model that focuses on how the uncertainty of the enforcement regime and 'upstream' fragmentation affect 'downstream' bargaining behavior during patent litigation. Our model extends the settlement negotiation game of Bebchuk (1984) and Spier (1992) by incorporating features of patent ownership fragmentation similar to those described by Lerner and Tirole (2004). Our model shows that, under quite general conditions, settlement agreements will be reached more quickly when the patent rights needed by the infringer are more fragmented (ownership is more dispersed) and in the more 'certain' enforcement regime associated with CAFC.

We test the main predictions of the model using an extended version of the dataset originally compiled by Lanjouw and Schankerman (2001a, 2004). This dataset combines information about the timing of patent case settlements from U.S. district courts with detailed data on the litigated patents from the U.S. Patent and Trademark Office. We find strong support: controlling for other characteristics, patent disputes litigated in the U.S. district courts are settled more quickly when infringers require access to fragmented external rights. We also find that the creation of CAFC substantially reduced settlement delays, and that this effect is stronger in lower courts where there was greater uncertainty of outcomes in the pre-CAFC regime. Finally, to assess the impact of patent thickets on the market for innovation, we use the parameter estimates results to study whether fragmentation of patent rights reduced the total settlement delay and find evidence that this may have occurred in some technology fields before the CAFC was introduced, but not in the later period.

The paper is organized as follows. Section 2 presents the model and the empirical predictions, and summarizes theoretical extensions that relax the key assumptions (details in appendices). Section 3 describes the data and variables used in the empirical work. In Section 4 we present and discuss the econometric results, with particular focus on how fragmentation of patent rights and CAFC affect the settlement delay per dispute. In Section 5 we use the parameter estimates to explore how the observed changes in fragmentation affect the total settlement delay, taking into account both the duration per dispute and the number of disputes. Brief concluding remarks follow.

1.1 Related Literature

Our paper is related to various strands of the literature in law and economics, and innovation. The first is theoretical research on pretrial negotiation and patent litigation. Bebchuk (1984) first showed how informational asymmetry, litigation costs and the value of the stakes affect the likelihood of settlement. Spier (1992) extends this model to a dynamic framework. Meurer (1989) studies settlement negotiations in a patent context and examines the impact of different rules for the allocation of legal costs. In these models, the legal dispute is treated as exogenous. More recently, Crampes and Langinier (2002) endogenize disputes by allowing the patentee to exert costly monitoring effort to detect infringements. Bessen and Meurer (2006) extend this model by also allowing the patent user to invest effort to 'invent around' the patent and thus avoid the dispute. Llobet (2003) studies the settlement of patent disputes in a cumulative innovation context, where the potential infringer enters with a superior product. All of these models study disputes between a single patentee and infringer.

Our model differs from these settlement games in that we introduce dispersion of intellectual property ownership. From this perspective our paper is related to earlier studies of patent pools. Shapiro (2001) shows that patent pools tend to raise (lower) welfare when patents are perfect complements (substitutes). Lerner and Tirole (2004) generalize this idea to intermediate levels of complementarity and show that the absence of independent licenses by pool members can be used by competition authorities to identify anti-competitive pools.

Our paper is closely related to the empirical literature on patent litigation. Lanjouw and Schankerman (2001) study the determinants of patent suits by examining the characteristics of litigated patents and their owners. Somaya (2003) shows that pre-trial settlement of patent suits is less likely when strategic stakes are high. Lanjouw and Schankerman (2004) show that litigation risk is much higher for patents owned by individuals and firms with small patent portfolios. Hall and Ziedonis (2007) study the link between CAFC and the level of litigation in the semiconductor industry. They find little evidence that semiconductor firms adopted a more aggressive stance towards patent enforcement after CAFC. But they observe an escalation in litigation against semiconductor firms brought by outside patent owners (which they interpret as attempts at 'ex post holdup' by such patent holders). Henry and Turner (2006) compare patterns of court decisions before and after CAFC both at the district and circuit courts levels, revealing a pro-patent shift associated with that institutional change.

Finally, our paper is related to empirical studies of patent thickets. Hall and Ziedonis (2001) show that semiconductor patenting rose sharply in the 1990's in response to the risk of hold-up generated by patent thickets. Ziedonis (2003) examines the relationship between firm-level patenting and a measure of the fragmentation of patent rights. She finds that patenting is higher when firms face greater fragmentation. Focusing on software firms, Noel and Schankerman (2006) show that greater fragmentation is associated with lower market value but higher R&D and patenting activity.

2 Model

In this section we develop a model to analyze how intellectual property fragmentation affects settlement bargaining behavior during patent litigation. The model extends the settlement games of Bebchuk (1984) and Spier (1992) by introducing dispersion of intellectual property ownership, building on Lerner and Tirole (2004). To simplify the exposition, we focus on a simple two period model. In Appendix 1 we extend the model to longer time horizons and more general payoff functions.

2.1 Intellectual Property

Consider a technology that builds on a set of features of existing, patented technologies held by other firms. We assume for simplicity that these features are covered by n patents symmetrical in importance and each owned by a different patentee. We refer to these as the 'constituent patents'. We assume that a licensee obtains a revenue of V if he uses all n constituent patents. Using only $m < n$ patents, he obtains a revenue equal to $\frac{m}{n}\theta V$. We interpret the parameter $\theta \in [0, n/m]$ as a measure of the complementarity among the n constituent patents. If these patents are perfect complements, $\theta = 0$; if they are perfect substitutes, $\theta = n/m$. The case $\theta = 1$ captures the setting in which the value of the technology is equally split among the n

constituent patents. We interpret the number of required patents, n, as a measure of the degree of fragmentation of patent rights.

As we show shortly, the case in which a potential user already has access to $n-1$ patents will play a crucial role in our analysis. When $m = n-1$, the value at stake in the n^{th} negotiation is the difference between the value earned using all n patents and the value obtained using only $n-1$ of them. We call this this difference the 'negotiation value' and define it as

$$z(n, \theta, V) \equiv V - V\frac{(n-1)}{n}\theta. \tag{1}$$

Equation (1) allows us to study how the value at stake is affected by both the level of complementarity among patents and the degree of ownership fragmentation.[3] Specifically, an increase in the degree of complementarity (lower θ), for constant n, increases the negotiation value of the n^{th} patent. An increase in the degree of fragmentation, n, for constant θ, reduces the negotiation value. These effects will play a central role in the predictions of the model.

The expression for the value at stake in equation (1) is similar in spirit to the marginal willingness to pay for a patent used by Lerner and Tirole (2004) in the context of patent pools. For simplicity, and to bring out the economic intuition more sharply, we impose linearity of $z(n, \theta, V)$ in V and θ. In Appendix 1 we show that all our results hold in a more general framework as long as $z(n, \theta, V)$ is decreasing in n and θ.

2.2 Litigation Game

We study litigation between a patentee and infringer who are both risk neutral. In this section we assume that the infringer has some private information about factual issues that is relevant to predicting the expected outcome of the trial (see Section 2.6 for alternative formulations). This assumption can be justified (and microfounded) in different ways. One approach is to assume that the infringer has more knowledge on how the validity of the patent can be challenged because of prior art not found by the patent office. Another possibility is to assume that the infringer knows better what proportion of his product is covered by the claims in the patent. Using this private information, the defendant estimates the likelihood that the patentee will

[3] We can also do comparative statics on how the total value of the technology, V, affects the negotiation value. We do not focus on this aspect because we do not have a satisfactory measure of V in the data.

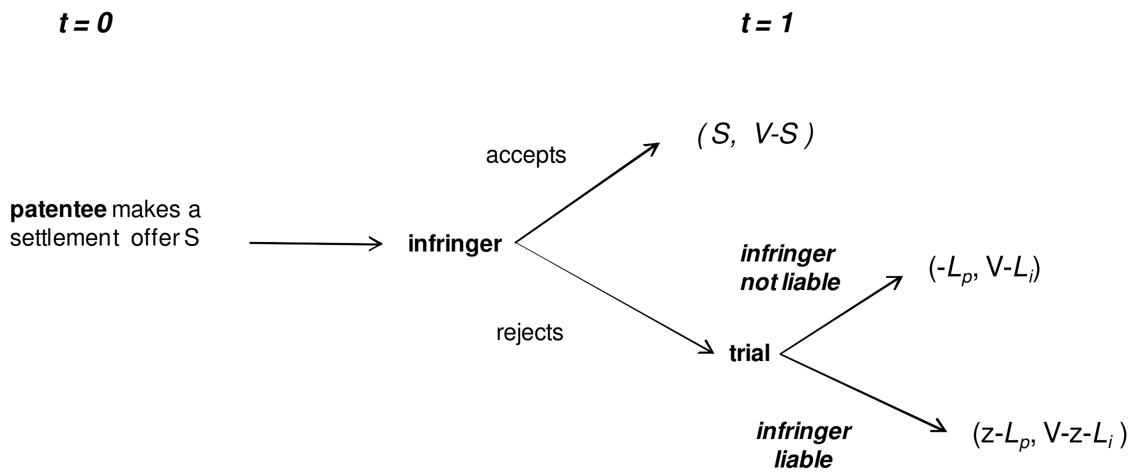

Figure 1: Settlement Bargaining Game

prevail at trial, which we denote by p. We refer to such an infringer as being of type p. The patentee does not know the infringer's type, but knows that p is uniformly distributed over the interval $[0, 1]$.[4]

The settlement bargaining game proceeds as follows. At time $t = 0$, the plaintiff makes a take-it-or-leave it settlement offer to the infringer (i.e., the license payment the infringer pays to the patentee). If he accepts the offer, the game ends. If the offer is rejected, a trial takes place at $t = 1$. Litigation is costly – if a trial takes place, the patentee and infringer incur costs of L_p and L_i, respectively. If the infringer is found liable, the court awards the patentee damages equal to $z(n, \theta, V)$. This represents the amount the defendant would earn from successful infringement of this patent, given that he had secured licenses to use the other $n-1$ constituent patents. This assumption is consistent with the *Unjust Enrichment* doctrine, as described by Schankerman and Scotchmer (2001). Under this doctrine, the patent owner is entitled to recover the profits realized by the infringer, on the theory that the infringer should not profit from his wrongdoing.[5] Figure 1 summarizes the timing of the game.

[4]It is easy to show that Proposition 1 below holds for any distribution $F(p)$ with increasing hazard rate.

[5]*Lost Profit/Reasonable Royalty* is the alternative liability rule used in the United States. Schankerman and Scotchmer (2001) point out that this doctrine involves a "circularity" between damages and licensing fee. From a technical point of view, this circularity generates a large number of equilibria. If we compute the average level of damages across the set of possible equilibria, one can show that average damages increase linearly in θ and decrease in n. In this sense, our framework is consistent with this alternative doctrine as well.

2.3 The Impact of Fragmentation

Applying backward induction, we first compute the settlement offer that the patentee makes at $t = 0$. The settlement (license fee) must be no larger than the sum of his expected damages and legal costs. Thus, a defendant of type p will accept a settlement S only if $S \leq pz(n, \theta, V) + L_i$, i.e. $p \geq (S - L_i)/z(n, \theta, V)$. Knowing this, the patentee's optimization problem is to maximize his expected profit by choosing a cutoff type, p^*, such that infringers above this cutoff accept the offer and those below reject it. Formally,

$$\max_p \ \pi = \int_p^1 [pz(n, \theta, V) + L_i]dy + \int_0^p [yz(n, \theta, V) - L_p]dy$$

subject to the constraint $p \in [0, 1]$. The first integral is the expected settlement value, and the second is expected damages net of the patentee's litigation cost. Defining $L \equiv L_i + L_p$, the unconstrained first order condition yields the following optimal cutoff type:[6]

$$p^* = 1 - \frac{L}{z(n, \theta, V)}.$$

In a two period model, because all types with $p < p^*$ reject the settlement, the uniform distribution over types implies that the expected length of a dispute is equal to the optimal cut-off:

$$E(t^*) = p^* = 1 - \frac{L}{z(n, \theta, V)}. \tag{2}$$

This allows us to summarize the relationship between fragmentation, complementarity and the expected settlement time in the following proposition:

Proposition 1 *The expected settlement time, $E(t^*)$, is non-increasing in n and θ.*

P roof. Using equations (1) and (2), it follows immediately that $\partial E(t^*)/\partial n \leq 0$ and $\partial E(t^*)/\partial \theta \leq 0$. ■

This proposition describes two properties of the expected settlement time in equilibrium. First, fragmentation (large n) tends to reduce bargaining delay in each dispute. The intuition

[6] Because of the uniform distribution of p, the expected win rate is $p^*/2$ that for high litigation costs can be arbitrarily close to zero. In a more general model, the win rate will depend on z, L and the distribution of p and will be equal to the average probability among defendant types lower than p^*. In principle it possible to generate parameter values that match any empirical win rate.

is that, provided the n patents are not perfect complements ($\theta \neq 0$), fragmentation reduces the negotiation value and hence the patentee's marginal benefit of screening, making early agreement more likely. Second, stronger complementarity among the required patents increases the expected settlement time per dispute. When patents are highly complementary, the surplus that the patentee expects to extract by litigating and holding-up the alleged infringer is larger. This increases expected damages, making early agreement less attractive. Therefore, for a given θ, an increase in n tends to reduce delay; similarly, for a given n, an increase in θ tends to reduce the expected delay.[7]

To summarize, Proposition 1 delivers two testable predictions about the relationship between the settlement delay per dispute and the degree of fragmentation and complementarity:

H1: Settlement negotiations will be shorter when the infringer requires access to more fragmented patent rights.

H2: Settlement negotiations will be longer for patents that have fewer substitutes (i.e., greater complementarity).

2.4 The Impact of CAFC

The Court of Appeal for the Federal Circuit (CAFC) was established in 1982 by the merger of the U.S. Court of Customs and Patent Appeals and the appellate division of the U.S. Court of Claims. The main purpose of the centralized appellate court was to bring greater uniformity in the enforcement of patent rights across circuits (Henry and Turner, 2006). In its first decision, *South Corporation et al. v. United States*, the CAFC adopted the holdings of the appellate division of the Court of Claims and the Court of Customs and Patent Appeals as binding precedents. This declaration was perceived as ending precedents from the circuit courts and unifying patent law at the national level.[8]

Many scholars have argued that CAFC generated a distinct 'pro-patent' shift (Hall and

[7] It is easy to show that the results in this Section also hold under the following extensions: 1) allowing parties to incur settlement costs in period zero, and 2) allowing the patentee and/or infringer's litigation costs to increase with the negotiation value (potential damages) – $L_p(z)$ and $L_i(z)$ – provided that the elasticity of total litigation costs with respect z is less than one.

[8] Various legal scholars also stressed the impact of CAFC on uniformity and predictability – e.g. Dreyfuss (1989). It is worth noting too that this reform was not directly associated with any major administrative changes at the district court level (Seamon, 2003).

Ziedonis, 2001; Jaffe and Lerner, 2004). This took the form of tougher evidentiary standards to invalidate patents (Henry and Turner, 2006), increased likelihood of large damage awards and wider use of preliminary injunctions (Merges, 1997). We study the impact of CAFC on *district court decisions.* We expect this pro-patent shift at the appellate court level to affect lower court decisions, since there is a reputational cost to lower court judges if they are reversed on appeal (Songer, Segal and Cameron, 1994; Klein and Hume, 2003).

In this section we examine how the introduction of CAFC altered the bargaining framework for disputes litigated after 1982. A natural way to model this is to assume that CAFC induced a stochastically dominant shift in the distribution of damages for the patentee. But this is not adequate because, while it captures the pro-patent shift, it does not capture the widely held view that patent decisions became more predictable after CAFC (first order stochastic dominance does not imply a reduction in variance). For ease of exposition, in this section we present an extremely simple specification that embodies stochastic dominance and a reduction in variance in outcomes. In Appendix 2 we show that our results are robust to a more realistic, and less stylized, specification.

We assume that there are two types of district courts. A proportion of them (α) is 'biased' in the sense that they always award full damages, $z(n, \theta, V)$, to the patentee independently of infringer's type p. The remaining fraction $(1-\alpha)$ is 'unbiased' in the sense that they correctly assess whether the infringement took place, i.e., the probability p. We also assume that the parties to the dispute know which type of district court is adjudicating their dispute.

In this simple setting, it is straightforward to compute the expected settlement delay (averaged across courts). If the court is not biased, the bargaining game is identical to the one studied in the previous section and the expected settlement time is $E(t^*)$. If the court is biased, there is no asymmetric information and the two parties settle immediately. Thus the expected settlement time, averaged across courts, is

$$E(t^B) = (1-\alpha)E(t^*). \tag{3}$$

Proposition 2 *The expected settlement time in the presence of court bias, $E(t^B)$, is decreasing in α. In addition $\dfrac{\partial^2 E(t^B)}{\partial n \partial \alpha} \geq 0$.*

P roof. It follows immediately from (3) and the fact that $\partial E(t^*)/\partial n \leq 0$. ■

The fact that $E(t^B)$ is decreasing in α suggests that the pro-patent bias associated with the introduction of CAFC facilitated early settlement agreements. The intuition is that pro-patent bias reduces the uncertainty about damage awards and thus diminishes the impact of asymmetric information on the bargaining process. It is interesting to note that it is not the *direction* of bias that affects settlement delay in our model, but the reduced uncertainty that bias entails. Any bias would reduce settlement delay as long as it reduces the variance of the distribution of damages.[9] What the direction of the bias (pro-patent, in our model) does is to affect the *terms of the settlement agreement,* increasing the patentee's expected payoff.[10] In the context of cumulative innovation, the settlement terms are important because they determine the structure of innovation incentives for initial and follow-on invention, as Green and Scotchmer (1995) have shown. In this paper we do not take a normative position on court bias (either pro- or anti-patent). We study only how such bias affects bargaining delay and thus technology diffusion.

The second part of Proposition 2 says that when there is less uncertainty about the outcome of the trial, the impact of the negotiation value (fragmentation reduces this value) on the likelihood of reaching a settlement agreement is reduced. To highlight intuition, consider the extreme case in which courts always award the patentee damages. In this case, all disputes will be settled immediately, independently of the level of fragmentation.

Proposition 2 provides two additional testable predictions about settlement delay:

H3: Settlement negotiations will be shorter for cases filed after the introduction of CAFC ('direct effect')

H4: The impact of fragmented external rights will be lower after the introduction of CAFC ('indirect effect').

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[9] Consider the case of 'anti-patent bias' where a fraction α of courts always award zero damages, independently of infringer type. Again there is no asymmetric information for biased courts, so parties settle immediately, and average settlement time is again $E(t^B) = (1-\alpha)E(t^*)$.

[10] To see this, define $\pi(p^*) \equiv (1-p^*)(p^*z + L_i) + \frac{(p^*)^2}{2}z - p^*L_p$. It is straightforward to show that the patentee's equilibrium payoff is $(1-\alpha)\pi(p^*) + \alpha z$ when there is pro-patent bias, and $(1-\alpha)\pi(p^*)$ with anti-patent bias.

2.5 Heterogeneity in Uncertainty across Circuit Courts

Before the establishment of CAFC, there were sharp differences across circuit court jurisdictions in their enforcement of patent rights. Henry and Turner (2006) document substantial heterogeneity in the frequency of validity and infringement findings, both across circuit courts of appeal and across district courts within any given circuit. These differences suggest that the impact of CAFC may have varied across circuit court jurisdictions, depending on the level of pre-CAFC uncertainty.

To address this issue, we extend our model by assuming that in each circuit the likelihood that the patentee will prevail at trial is uniformly distributed over the interval $\left[\frac{1}{2}(1-\lambda), \frac{1}{2}(1+\lambda)\right]$ with $\lambda \in [0,1]$. An increase in λ enlarges the variance of the distribution while preserving its mean.[11] We interpret the parameter λ as a measure of the level of pre-CAFC uncertainty in court outcomes (including appeals), and we conduct comparative statics in λ to study the differential impact of CAFC across circuits.

In this setting the optimal cutoff type becomes

$$p^*(\lambda) = \frac{1}{2} + \frac{\lambda}{2} - \frac{L}{z}$$

which implies an expected settlement time equal to

$$E(t^*(\lambda)) = 1 - \frac{L}{z\lambda}. \tag{4}$$

After CAFC the expected settlement time is

$$E(t^B) = (1-\alpha)E(t^*(\lambda)). \tag{5}$$

Proposition 3 *The expected settlement time is increasing in* λ*. In addition* $\dfrac{\partial^2 E(t^B)}{\partial\lambda\partial\alpha} < 0$.

P roof. It follows immediately from formulas (4) and (5). ■

As first pointed out by Bebchuk (1984), "spreading out" the distribution of types increases the expected settlement time because it amplifies the differences among types in the expected outcome of a trial. Moreover, the proposition implies that the impact of CAFC is larger in circuits where the variance of p is greater and suggests the following testable prediction:

[11] Bebchuk (1984) shows that the results in this section are valid for more general (non-uniform) mean-preserving shifts.

H5: The impact of CAFC is stronger in circuits where there is larger uncertainty in court outcomes in the pre-CAFC regime.

2.6 Main Assumptions and Modelling Extensions

In this section we discuss the main assumptions of the baseline model and the robustness of the empirical predictions to a variety of alternative specifications and generalizations (detailed derivations are presented in the appendices).

First, we assumed that the litigation game lasts only two periods. Because of this assumption the expected settlement time equals the optimal cutoff type and has a very simple and intuitive formula. In Appendix 1 we relax this assumption and allow for T periods of bargaining prior to the court judgment. We show that the expected settlement time of this extended game also decreases in n and in θ because the patentee is willing to screen for a longer time when the value at stake is high (n and θ are low).

Second, we assumed that the infringer has private information about the likelihood of prevailing at trial. In Appendix 2 we study the game in which the patentee is the informed party. Changing the identity of the informed player converts the screening model into a signalling game but does not affect the main results. Because the incentives to signal are greater when the value at stake is large, the expected settlement time decreases in n and θ and testable predictions H1-H5 hold in this alternative setting.

Third, in Appendix 3 we introduce product market competition between the patentee and infringer. Specifically, we assume that the patent gives greater profit to the patentee and that this advantage is smaller when patent rights are more fragmented and complementarity is weaker. We find that if competition is not too intense and legal costs are large enough, the patentee has an incentive to settle the dispute and that the expected settlement time decreases in n and θ. However, if competition is very intense and legal costs are not large, the patentee will avoid licensing and will always go to trial thus 'blocking' access to the patent. If the patentee's profits are sufficiently responsive to n, then this 'blocking' behaviour becomes less likely when patent rights are more fragmented.

Fourth, in Appendix 4 we extend our model to endogenize disputes that are litigated. We do this in two ways. First, we introduce a pre-suit settlement stage (the baseline model studies only post-suit settlement). Second, following Crampes and Langinier (2002), we assume that the patentee sustains a cost to identify an infringer. Our results show that disputes are both less likely to be discovered and less likely to be litigated when fragmentation is greater and complementarity is weaker. This extended model implies that we should observe a smaller number of suits filed per-patent in technology areas where ownership is more fragmented.[12] This model also implies that CAFC has two impacts: it increases the number of discovered disputes because of pro-patent bias, but at the same it facilitates pre- and post-suit settlement because of greater certainty in enforcement. Because of these countervailing effects, the extended model has no empirical prediction about how the number of litigated disputes changes after CAFC.

Fifth, in Appendix 5 we show that there is no loss of generality in focusing on the *n-th* negotiation as long as (i) the infringer does not have limited assets (ability to pay damages) and (ii) the patentee always licenses in equilibrium (i.e., product market competition between the two parties is not too intense). If both conditions hold, the comparative statics in fragmentation and complementarity go through unchanged – expected settlement time declines in n and θ. If either condition (i) or (ii) fails to hold, then the expected settlement time still decreases in n but may not decrease in θ.

Lastly, we discuss alternative ways of modeling the effects of CAFC. In Appendix 6 we model CAFC as a shift in the distribution of the probability the patentee prevails at trial. We use a general formulation in which the post-CAFC distribution has a higher mean, lower variance and first-order stochastically dominates the pre-CAFC distribution. This generalization shows that CAFC has two countervailing effects on litigants' incentive to settle. On one hand, it facilitates settlement because it reduces uncertainty of outcomes, but at the same time it increases the incentive to litigate because the expected damages are higher. We show that the first effect dominates and CAFC reduces settlement time, provided that litigation costs are not too large.

[12] In principle this implication can be tested empirically. However, we cannot test it using our data because our fragmentation measure is specific to the infringer rather than the patent. In order to test this prediction we would need a measure of fragmentation for a "representative disputant" (see Lanjouw and Schankerman, 2004). While interesting, this task is beyond the scope of this paper.

3 Description of Data

The empirical work is based on two data sets: patent litigation data from the U.S. federal district courts, and the NBER patent dataset. The patent litigation dataset was compiled by Lanjouw and Schankerman (2001a, 2004). This dataset matches litigated patents identified from the Lit-Alert database with information on the progress or resolution of suits from the court database organized by the Federal Judicial Center. The dataset contains 9,219 patent infringement cases filed during the period 1975-2000 and terminated before 2001. For each of these case filings, the dataset reports detailed information on the main patent litigated (although there may be other patents listed), the patentee, the infringer and the court dealing with the case. Following Lanjouw and Schankerman, we focus on the main patent in dispute (when multiple patents are listed).

We extended the Lanjouw and Schankerman dataset by collecting information on the identity of the infringers. We manually matched infringer names listed in the court data with assignee names in the NBER patent dataset. We were able to match the infringer to a patent assignee for 5,131 infringement cases. In most cases where matching was not possible, the names of the infringers suggest they were individuals or small firms. This matching procedure allows us to identify the patents owned by the infringing parties, and thus to construct the size of their patent portfolios and other information at the time of litigation. In this respect, our data is more comprehensive than those used in earlier studies, where information on infringers was not present (Lanjouw and Schankerman, 2001a, 2004) or was limited to specific industries (e.g. semiconductors in Hall and Ziedonis, 2007; drugs and computers in Somaya, 2003).

The main variables used in the empirical analysis are described below.

Dispute Duration: This is the endogenous variable in the analysis. It is defined as the number of months elapsed between the original case filing date and the case termination date, as reported in the district court data. This variable indicates the time period required to reach the settlement agreement or, in its absence, the court judgment. On average, it takes 18 months and 18 days to settle a patent litigation case. However, the distribution of length is sharply skewed (Figure 1): 25 percent of cases settle within 5 months, but 25 percent last more than 24 months.

We use the following control variables to capture the main ingredients of our bargaining model.

Fragmentation1: Let $p_{\tau T}$ denote a patent in technology class τ which is litigated at time T, and let j denote the infringer (we use the 36 two digits categories as defined in Hall, Jaffe and Trajtenberg (2001)). We identify the set of the infringer's patents in class τ with application year within five years in either direction of the suit, say $\{p_{j\tau t}\}_{T-5\leq t\leq T+5}$. We then identify the share of citations of these patents in each of the 417 classes defined by the USPTO, and compute the fraction of citations to patents belonging to class n, w_{jnT}. For each class we compute the share of patents accounted for by the top four patentees in the same 10-year window, $C4_{nT}$. Using this information we construct the following fragmentation measure:

$$Fragmentation1_{j\tau T} = 1 - \sum_{n} w_{jnT} C4_{nT}. \tag{6}$$

For 25 percent of the infringers in the sample, we do not observe any patent in the technology class of the litigated patent with application year in a ten year window around the suit (this is because they are very small, not missing information). For these infringers, following Lanjouw and Schankerman (2004), we calculate a concentration index using the citations of the *litigated* patent as weights for the fragmentation measure. A dummy variable, **Missing**, is set equal to one for observations for which this correction was performed.

As a robustness check we construct an alternative measure:

Fragmentation2: As in the previous measure, we construct the set $\{p_{j\tau t}\}_{T-5\leq t\leq T+5}$. We then identify the citations of these patents that refer to other (distinct) assignees. Let C_{kj} denote the number of these citations that refers to assignee k. Following Ziedonis (2004), we construct the following fragmentation measure:

$$Fragmentation2_{j\tau T} = \left[1 - \sum_{k\neq j}\left(\frac{C_{kj}}{C_j}\right)^2\right]\frac{C_j}{C_j - 1} \tag{7}$$

where C_j indicates the total number of non-self, backward citations.[13]

Both fragmentation measures attempt to capture the degree of concentration of patent rights. The idea is that when a firm's patents are related to technology areas with few paten-

[13] As recommended by Hall (2002), we use the term $C_j/(C_j - 1)$ to remove the downward bias of the Herfindahl index.

tees, that firm is more likely to be involved in a smaller number of negotiations and disputes (Ziedonis, 2004; Noel and Schankerman, 2006). The two measures differ in the way they identify the technology areas in which the firms obtain their patented inputs. Fragmentation1 uses the infringer's backward citations to identify these technology classes. Fragmentation2 uses the patentees actually cited as a proxy for the number of required negotiations.[14],[15]

Our data contains a substantial minority of infringers with very small patent portfolios (e.g., 50 percent have fewer than four patents in the technology area in a ten year window). For these cases we considered it more sensible to infer the degree of fragmentation from the entities operating in their technology area rather than from the entities cited. For this reason, we use Fragmentation1 as primary measure of ownership dispersion, and Fragmentation2 as a robustness check on the results.

Complementarity: Let $p_{\tau t}$ denote a litigated patent with application year t and belonging to the technology class τ. Our complementarity measure is the ratio between the non-self citations that $p_{\tau t}$ has received up to the year 2002 from patents in technology class τ and the non-self citations received by all patents in τ that have application dates in a 10 year window from the application of the litigated patent. Formally, let $C^{\tau}_{p_{\tau t}}$ denote the number of non-self citations received by $p_{\tau t}$ from other patents belonging to τ. Our measure is:

$$Complementarity_{\tau t} = \frac{C^{\tau}_{p_{\tau t}}}{\sum\limits_{\substack{b \in \tau \\ t-5 \leq T < t+5}} C^{\tau}_{b_{\tau T}}}. \tag{8}$$

In the analysis that follows, we multiply this index by 1000. With this normalization, *Complementarity*=α means that the citations received by the litigated patent account for α percent of the citations received by patents in a *one-year* window in the technology field.

This measure is indirect and imperfect. Ideally, we would like to measure complementarity more directly, but this would require detailed information about the actual set of patented

[14]To see the difference, consider the case in which all backward citations of a firm go to a single patentee that operates in a technology area in which ownership is very fragmented. In this case *Fragmentation1* will indicate the infringer as operating in a very fragmented area, whereas *Fragmentation2* will show that the infringer deals with only one patentee

[15]We also constructed a third measure of fragmentation using the distribution of the infringer's patents across classes, rather than the infringer's patent citations, to identify the technology areas in which the firm obtains its inputs. This measure is highly correlated with the other measures, and the econometric results using it are very similar.

inputs used by each firm in the sample. The number of citations received by a patent has been widely used as a indicator of 'importance' of a patent. Our complementarity measure reflects the importance of the litigated patent *relative to* other patents in the same technology field. This measure is based on the idea that the greater is the relative importance of the patent, the more difficult is for the infringer to find a substitute patented input in that technology field. Thus we associate a higher value of the measure with a lower value of the parameter θ in the model.

Patent value: We use the number of total citations received by the litigated patent from patents in all technology fields (up to the year 2002) as a measure of the value of the litigated patent. This measure is conceptually and empirically distinct from the complementarity index, which measures the relative importance of the patent in its own technology field. The sample correlation between our measures of patent value and complementarity is only 0.16.

CAFC: We construct a dummy variable for patent suits filed after the creation of the specialized patent appellate court, which was introduced in 1982. The dummy takes value of one for cases filed from 1982 onwards. We experimented with alternative timings (to reflect lags in the effects of CAFC) but the empirical results were very similar.

High-Variance Circuits: We use information on district court decisions and circuit court appeals for the period 1953-1981 (Henry and Turner, 2006) to construct a dummy variable for cases litigated in the top three (alternatively, four) circuits with greatest uncertainty about court outcomes. We treat the court decision as a Bernoulli process. Let p denote the probability that the patentee 'wins' in a given district court. Then the variance on outcomes for that court is given by $p(1-p)$. We use two alternative definitions of a 'win': i) the fraction of cases where the district court finds the patent 'valid and infringed' and ii) this fraction adjusted by the observed rates of appeal and circuit court affirmation of the pro-patent decision.[16] Both approaches identify the same top four circuit courts in terms of variance: the 4th, 5th, 7th and 10th circuits.

Duplicate cases: In the data we observe distinct patent suits that involve the same

[16] Specifically, let q denote the probability that the patent is held "valid and infringed," r be the probability the decision is appealed, and ω denote the probability the lower court decision is affirmed. Under the second method, the patentee win rate is given by $p = q(1-r) + qr\omega + (1-q)r(1-\omega)$.

patentee, the same infringer and the same patent and which are recorded in the same year. Sometimes these cases have been re-entered with the same docket number, sometimes with a different one. Part of this re-entry appears to be associated with a change in the litigation venue. We generated a dummy variable to control for these duplicate cases.

Technology field dummies: Following Lanjouw and Schankerman (2004), we control for the technology field of the litigated patent. We use the following eight broad technology areas (percent of sample): Pharmaceuticals (3.8%), Other Health (8.8%), Chemicals (14.4%), Electronics excluding computers (21.3%), Mechanical (30.9%), Computers (1.0%), Biotechnology (0.7%), and Miscellaneous (19.1%).

District court dummies: We use a complete set of dummy variables to control for the district of the court in which the patent is litigated. There are 89 district courts in the 50 states and all of them are represented in our sample.

Table 1 presents descriptive statistics for the main variables.

In Table 2 we examine the key predictions of the bargaining model using the raw data. The top panel shows that the dispute duration is negatively related to fragmentation. For the entire sample period, the mean dispute duration for patents with fragmentation index above the median is about 10 percent lower than for those below the median. The difference is larger for cases filed before the formation of CAFC, consistent with the prediction that fragmentation is less important when there is less uncertainty over court outcomes. The lower panel of the table shows that dispute duration is positively related to complementarity. For the whole sample period, the mean dispute duration for patents with complementarity index above the median is about 40 percent longer than for those below the median.[17] This table also shows that there is a sharp drop in the mean dispute duration for cases filed in district courts after the formation of CAFC.

These simple mean comparisons are confirmed by the sample distributions of dispute durations (survival curves) in Figure 2. The distribution for patents with below-median fragmentation stochastically dominates the one for above-median fragmentation (the reverse holds

[17] We also find that dispute duration is longer for more valuable patents (not shown in the table). The mean duration for cases in the fourth quartile of the distribution of patent citations is about 30 percent longer than for those in the first quartile.

for complementarity; figures omitted for brevity). In addition, the distribution of dispute duration for cases filed before CAFC stochastically dominates the one for cases after CAFC.

The observed reduction in dispute duration after CAFC was not due to a decline in court case loads or faster adjudication by courts. the number of patent suits per year increased dramatically – from about 185 before CAFC to 550 in the period 1983-94. Moreover, as Table 3 shows, there was actually a *decline* in the fraction of cases reaching final adjudication at trial. Prior to the introduction of CAFC, 17.2 percent of all patent suits reached final adjudication, as compared to only 5.9 percent afterwards, and this reduction occurred in all technology fields (except Miscellaneous). Furthermore, there was a substantial increase in the proportion of cases settling very early, before the pre-trial hearing is reached. This is exactly what we would expect since CAFC increased the likelihood of the patentee prevailing on appeal, and thus reduced the incentive for the alleged infringer to hold out (at great cost) for a lower court decision.

4 Empirical Specification and Results

4.1 Econometric Specification

To study the data on the duration of disputes, we adopt a proportional hazard model with an exponential specification:

$$\begin{aligned} \ln h_{ijct} &= \alpha_0 + \alpha_1 Fragmentation_{ijt} + \alpha_2 Complementarity_{it} + \\ &\quad \alpha_3 CAFC_t + \alpha_4 CAFC_t * Fragmentation_{ijt} + \alpha_5 X_{it} + \omega_c + \eta_t + \varepsilon_{ijct} \end{aligned} \tag{9}$$

where h denotes the (age-constant) hazard rate, i, j, c and t represent the patent being sued, the infringing firm, the district court hearing the case, and the year the suit is filed, respectively, X is a vector of control variables for other factors that affect bargaining delay (including patent value), ω_c represents a full set of court dummy variables, η_t is a partial set of year dummies (explained below), and ε_{ijct} is a mean zero random error. For the baseline results, we assume that ε_{ijct} is independent over i, j, c and t.[18] A *negative* coefficient on a regressor in the hazard

[18] We also check significance of parameter estimates using standard errors that allow for clustering across patents and patent owners. Such correlation can arise from two sources. First, there are instances in the data of multiple cases involving the same patent, so any unobserved heterogeneity at the patent level would induce

rate model means that the variable makes it less likely that negotiations end, which corresponds to a *longer expected settlement delay.* The model implies the following predictions in this specification: fragmentation reduces bargaining delay ($\alpha_1 > 0$), complementarity increases delay ($\alpha_2 < 0$), CAFC reduces delay ($\alpha_3 > 0$) and also reduces the impact of fragmentation on delay in absolute value ($\alpha_4 < 0$). The exponential specification imposes a constant (baseline) hazard rate, but the results are nearly identical for the more flexible Weibull specification which allows for an age-dependent hazard rate.[19]

The baseline specification embodies two sets of restrictions that should be noted. First, most of the variation over time in settlement delays is captured through the CAFC dummy variable (equal to one for $t \geq 1982$). This is a constrained version of a more general specification which allows for an unrestricted set of year dummies for 1976-2000, say $\{\eta_t\}$, and their interactions with the fragmentation measure, $Fragmentation * \{\eta_t\}$. We began by estimating this unrestricted specification – Figure 3 plots the estimated year effects (normalized to zero in 1975). They show no trend during 1976-81, a sharp drop in 1982, which was when CAFC was established. We do not reject the joint hypothesis that the coefficients on the dummies are zero for 1976-1981 and equal to each other for 1982-1991 (*p-value*= 0.08). We therefore introduced the additive CAFC dummy and allowed year dummies only for 1992-2000.[20] We then tested, and do not reject, the hypothesis that the coefficients on the interaction terms $Fragmentation * \{\eta_t\}$ are zero for 1976-1981 and equal to each other for 1982-2000 (*p-value*= 0.08). This provides support for our baseline specification, where year dummies η_t are included only for 1992-2000.

Second, the baseline specification assumes that the coefficients on the fragmentation measure and its interaction with the CAFC dummy are the same across technology fields. We tested these restrictions using six broad technology categories and do not reject them

correlation. Second, there are instances of the same plaintiff (patentee) involved in multiple suits over different patents, so unobserved heterogeneity at the patentee level can also induce correlation across patents (e.g. some firms are more aggressive than others in enforcing their patent rights). Thus we also compute robust standard errors with clustering at the patent, or patentee (plaintiff), level.

[19] The Weibull is a two-parameter distribution with the (baseline) hazard function $h(t) = \lambda\gamma t^{\gamma-1}$.The exponential case arises when $\gamma = 1$. In the baseline econometric specification, the point estimate of γ is 1.28 (s.e. = 0.013), so we formally reject the exponential restriction in favor of the Weibull with an increasing hazard rate.

[20] These free dummies are needed because there is a distinct decline in average settlement delay after 1997), which is partly due to truncation in the data (we only observe cases that have been settled by 2000). We decisively reject the hypothesis that these free dummies are jointly zero.

$(p - value = 0.17)$.

The key determinants of bargaining delay in our model – fragmentation and complementarity – are difficult to measure, and the constructs we use are likely to contain random measurement error. The associated attenuation bias will cause us to underestimate the impact of fragmentation and complementarity on expected settlement duration, so our estimates are conservative in this sense.

4.2 Baseline Empirical Results

Table 4 reports the baseline parameter estimates for the hazard model, together with the implied marginal effects of each control variable on the expected dispute duration.[21] In column (1) we include only the three key variables – Fragmentation, Complementarity and CAFC – and the year dummies for 1992-2000. The results are consistent with the predictions of the model. First, the estimated coefficient on fragmentation (α_1) is positive and significant, confirming hypothesis $H1$: when infringers require access to more fragmented patent rights, disputes are settled faster (higher hazard rate). A one standard deviation increase in the fragmentation index reduces dispute duration by 22 days. Second, stronger complementarity among patents increases the duration of disputes (reduces hazard rate), supporting hypothesis $H2$. The point estimate of α_2 is negative and significant, and implies that a one standard deviation increase in the complementarity index increases duration by 23 days. Third, the duration of disputes was sharply reduced by the establishment of the specialized appellate court, CAFC. The positive and significant point estimate of α_3 implies that CAFC reduced the average settlement delay by 6 months. This finding supports the hypothesis that the greater predictability in enforcement associated with CAFC facilitated settlement.

In columns (2)-(4) we add control variables. Column 2 includes technology field and district court fixed effects. In this specification the estimated impact of fragmentation is 30 percent larger than without fixed effects. There is almost no change in the estimates for complementarity and CAFC. Not surprisingly, the court fixed effects are highly significant (we

[21] Two points should be noted. First, for all these regressions we present robust standard errors. We also allowed for clustering at the patentee level and at the patent level (for cases where there are multiple suits on the same patent). The clustered standard errors are very similar, and statistical significance is unaffected.

Second, we obtain very similar estimated marginal effects and significance levels if we use a simple linear specification estimated by ordinary least squares.

reject the null that they are zero, *p-value* < 0.01). This is consistent with studies by legal scholars which show that there is substantial variation in the degree to which federal district courts seem to favor patent holders (Moore, 2001).[22]

Column (3) adds a control for patent value (citations count) and dummy variables to account for cases where there are duplicate disputes and for (small) infringers for whom we were unable to compute the fragmentation index. The estimated coefficients on Fragmentation, Complementarity and CAFC are robust to the inclusion of these additional controls. As expected, we find that negotiations over more valuable patents take longer to settle. A one standard deviation increase in the citations count extends dispute duration by about 0.8 months. However, as we show in the next section, this estimate corresponds to patents of an 'average' age. Taken together with the finding by Lanjouw and Schankerman (2001a, 2004) that more valuable patents are much more likely to be involved in litigation in the first place, we conclude that patent enforcement and licensing are most problematic precisely for the patents that matter most. Moreover, our finding that both patent value and complementarity independently affect dispute duration suggests that our measure of complementarity is not just a proxy for value. Finally, the estimated coefficients on the dummy variables for duplicate and missing cases (involving very small infringers) are statistically significant. Duplicate cases take much longer to settle (13 months), which is not surprising since they are likely to be more complex. Interestingly, the Missing dummy indicates that cases that involve very small infringers (who have no patents in the same technology subclass as the infringed patent) settle faster, by about 1.1 months.

The model predicts that the reduction of uncertainty associated with the centralized appellate court should reduce the impact of fragmentation on dispute duration. In column (4) we introduce the interaction between Fragmentation and the CAFC dummy to test this prediction. We treat this as the baseline specification. The estimated coefficient on the in-

[22] Given this variation, there is the possibility that the disputants may 'venue-shop' for courts sympathetic to their position, to the extent this is allowed by law. If this occurs and both parties are aware of court 'bias', this should facilitate earlier settlement. However, there is no reason to believe that venue shopping should be correlated with our measures of fragmentation or complementarity, and thus it should not introduce any bias in the estimated coefficients on these variables. If the extent of venue-shopping changed at all after CAFC, we would expect it to have declined since there is less uncertainty about the outcome on appeal. Thus our estimate of the impact of CAFC on dispute duration should be conservative.

teraction term is statistically significant and strongly confirms this prediction. The marginal effect of fragmentation prior to CAFC is -55.4, but after CAFC it drops to -7.2 (which is statistically different from zero, $p - value = 0.03$). Allowing for the interaction increases our estimate of the impact of CAFC on dispute duration. The net effect of CAFC, evaluated at the mean value of fragmentation, is to reduce dispute duration by 7.8 months. This is larger than the estimate for column (3) where we do not allow for the interaction (reduction of 5.3 months). Interestingly, in our baseline regression we find no strong evidence that settlement delay varies across technology fields (we do not reject that the technology fixed effects are zero, $p - value = 0.09$).[23]

As discussed earlier, there was substantial heterogeneity across circuits in the uncertainty of court outcomes before CAFC. The model predicts that the effect of introducing CAFC should be stronger for district courts located in circuits where the uncertainty over damages was larger. To test this prediction, in column (5) we introduce an interaction between the dummy variable for CAFC and a dummy variable for the top 3 circuit courts with the highest variance in outcomes. This is exactly what we find: the estimated impact of CAFC is almost twice as large for the high-variance district courts. This finding gives us additional confidence that the CAFC effect is not simply due to some unobserved factor that reduced settlement duration, since we find that the reduction is systematically related to the degree of pre-CAFC variance in court outcomes.

All of the preceding specifications include a full set of district court dummies. There are many reasons district courts might differ in their average settlement durations, including case loads and fiscal constraints. But the model predicts one factor that should play a role is the degree of uncertainty over court outcomes. This should not only interact with the impact of CAFC, as discussed above, but also should affect settlement duration in the pre-CAFC regime. To examine this hypothesis, in column (6) we replace the district court dummies with a single dummy variable for the high-variance circuit courts. We expect the estimated marginal effect of this dummy variable to be positive, and that is what we find. The point

[23] Bulow (2004) points out peculiar settlement agreements that are sometimes observed in pharmaceutical patent infringements. As a robustness check, we dropped cases involving pharmaceutical patents and found that the estimated parameters were similar to the baseline results.

estimate implies that settlement negotiations in these high variance circuits lasted four months longer than in other circuits. At the same time, we reject the restrictions imposed by this more parsimonious specification ($p - value < 0.001$). This is not surprising, and simply confirms that there are other factors accounting for variation across district courts. But it is interesting to note that the estimated coefficients on the other variables are very similar in the more restricted specification (compare columns (5) and (6)), which indicates that these other factors are evidently not correlated with the variables of interest in the model.

A possible concern regarding the interpretation of the CAFC effect is that the reduction in settlement duration could be due to a wider use of preliminary injunctions by courts after the introduction of CAFC (Lanjouw and Lerner, 2001) rather than a reduction in uncertainty. To address this, we obtained annual data from 1983-93, and the average for the pre-CAFC period, on the percentage of requests for preliminary injunctions that were granted in district court patent cases (Cunnigham, 1995). These data show an increase in the proportion of granted injunctions after CAFC (from 32% to 53%). We re-estimate the baseline specification of our model including this new variable to control for the impact of changes in the use of preliminary injunctions. We find that greater use of preliminary injunctions has a statistically significant impact in reducing settlement delay (not reported for brevity). This finding is interesting in its own right, and all of our earlier key are robust. A simple comparison of the estimated coefficients with those of the baseline regression suggests that about 35% of the reduction in settlement delay in the post-CAFC period can be attributed to the preliminary injunction effect.

4.3 Extensions and Robustness

In this section we examine extensions and robustness of the baseline specification (Table 5). The first experiment involves a generalization of the way in which patent value affects dispute duration. We have controlled for the value of the patent using a citations measure. However, the stakes in the negotiation (potential licensing value), and thus the expected dispute duration, should also depend on the age of the patent for two reasons: first, there is age-related depreciation in the private returns from patented innovations (Schankerman, 1998) and, second, there is less time remaining until statutory expiration of the patent. To capture both effects, we write patent value at age a as $V_a = Ve^{-\delta a} \simeq V(1-\delta a)$. Assuming the true specification of the model involves V_a, if we include both V (citations) and an interaction term $V * a$ in the regression, the coefficient on the interaction term should be negative and the ratio between the coefficients yields an estimate of δ. The results in column (1), Table 5 confirm that the dispute duration is smaller for older patents, controlling for their citation count. Moreover, the point estimates show that, for young patents, the impact of value is about two times larger than when we do not incorporate the age effect (column (4), Table 4). For new patents ($a = 0$), marginal effect of value is 0.056, and a one standard deviation increase in value raises dispute duration by 1.4 months. Moreover, the implied estimate of δ is 0.054, implying the impact of value on dispute duration disappears after about 20 years.

Second, there is a concern that our results might be driven by serial litigants, either patentees or infringers involved in multiple disputes. In our sample there are 2,154 distinct patentees, with a mean number of disputes per patentee of 1.47 (median=1, maximum=24). The distribution is highly skewed - the top one percent of patentees accounts for 6.2 percent of disputes. The numbers are similar for the distribution of infringers. We take two approaches to address this concern. First, we include dummy variables for serial patentees and infringers (the top one percent) and re-estimate the baseline specification (column (2) in Table 5).[24] Second, we simply drop cases involving the serial patentees or infringers (reducing the sample size by 8 percent). In both approaches the estimated parameters are similar to the baseline results. The coefficient on the dummy variables are significant at the 10 percent level and, interestingly, suggest that the disputes take longer to settle (by nearly 4 months) when brought by a serial patentee, but are settled more quickly (by 3.5 months) when a serial infringer is involved. This finding is consistent with the idea that serial patentees are those who aggressively enforce their intellectual property, and serial infringers are those who only engage in licensing negotiations when forced to do so by patent suits. [25], [26]

[24]We also tried including a dummy for cases involving both serial patentee and infringers, but the coefficient was not statistically significant ($p - value = 0.11$).

[25]It is also worth noting that the correlation between the number of times an infringer is litigated and fragmentation is negative (-0.124). This negative correlation is consistent with a prediction of the extended model in which the discovery of disputes is endogenous (Appendix 4).

[26]The baseline coefficients are very similar if we drop all the duplicate cases involving the same patentee,

Third, we examined whether the size of the litigants' patent portfolios affects their ability to settle disputes. Lanjouw and Schankerman (2004) show that firms with larger patent portfolios are much less likely to be involved in patent suits, indicating that portfolios provide bargaining chits and facilitate tacit cooperation in settling disputes without recourse to courts. One might think that a similar mechanism operates for settling disputes after suits are filed. To study this, and to check robustness of our key findings to this extension, we included measures of the patent portfolios (cumulated patents over the preceding 20 years) held by the patentee and infringer, as well as the relative portfolio size. We found no significant impact for these *portfolio size* measures and no change in the other coefficients (not reported). However, we do find evidence that *symmetry in portfolio sizes* matters at the extremes of the size distribution (column (3), Table 5). Disputes are significantly shorter when both litigants have either very large patent portfolios ($\geq$1000 patents) or very small portfolios ($\leq$ 5 patents). For large firm pairings, the dispute duration is shorter by 4.4 months; for small firm pairings, by 1.3 months. The finding for large firms is consistent with the interpretation of Lanjouw and Schankerman, while the small firm finding suggests a role for cash constraints in the settlement process. However, we leave a more careful study of this topic for future research.[27]

Fourth, we examine whether settlement delays are affected by the resources of the court. To do this, we collected data on the total number of cases filed (not just patent cases) in each year and the number of authorized judgeships for each of the federal district courts over the period 1975-1998 (source: Federal Court Management Statistics). We generate a new variable 'Caseload' defined as the total number of cases filed divided by the number of judges for each district court in each year. The average caseload declines quite sharply over the sample period (averaged over district courts), from 155.6 cases filed per judge in 1975 to 90.2 in 1998. But the trend does not show a drop in 1982, when CAFC was introduced: the number of cases per judge declines from 1975-79 and then rises until 1984, and then again declines. In column (4) of Table 5 we add the caseload variable to the baseline specification. Interestingly, the caseload

infringer and patent in the same year.

[27]The correlation between infringer patent portfolio size and fragmentation is -0.24 (p-value<.001). But the quantitative differences in fragmentation are not large – the value of the fragmentation index is 0.892 for the lowest size quartile and 0.852 for the largest quartile.

coefficient is statistically significant and indicates that higher caseload is associated with longer settlement delay. At the same time, controlling for caseload does not affect the magnitude or significance of our key variables – fragmentation, complementarity and CAFC.[28]

Fifth, the measure we use for patent value is the total citation count (including self-cites) received by the litigated patent. Unfortunately, for 29 percent off the litigated patents the NBER database does not allow us to distinguish between self-and non-self citations received. As a robustness check, we re-estimate the baseline specification using only non-self citations when available and total cites for the other 29 percent, and introducing an additive dummy for the latter. The parameter estimates are nearly identical to the baseline results (not reported, for brevity).[29]

Sixth, we check robustness of the results to the alternative fragmentation measure, $Fragmentation2$ (column 5). The qualitative findings are the same, but the impacts of fragmentation and CAFC are somewhat smaller. The point estimates imply that a one standard deviation increase in $Fragmentation2$ reduces dispute duration before CAFC by 1.8 months, as compared to about 3.9 in the baseline specification. There is no statistically significant impact post-CAFC ($p - value = 0.34$), whereas in the baseline specification there was a small, but statistically significant, negative impact. Finally, the estimated impact of CAFC, evaluated at the mean fragmentation, is -7.0 months, very similar to the estimate in column (4) of Table 4.[30]

[28] In addition, we have information on the caseload by circuit court. We observe that average caseload is lower for the post-CAFC period in each circuit court.

[29] As explained in Section 3, for about 25 percent of cases the infringer has no patents in the technology sub-class of the litigated patent (within a 5 year window). For these cases, to construct the fragmentation measure we use the citations of the *litigated patent.* In the baseline estimation, we included a dummy variable (**Missing**) to identify observations with this correction. But probit regressions (not reported) indicate that these observations are not random – they are more likely to involve patents with low value and in areas where ownership is not concentrated. As additional robustness check, we restricted the sample to non-missing observations and re-estimate the baseline specification. The results are very similar to those reported in the text.

[30] We also use an alternative fragmentation measure constructed using the 4-digit international patent classification which identifies about 4,200 different technology fields. Unfortunately, the NBER dataset reports IPC information only for patents granted after 1975. This means that we cannot use citations that refer to pre-1975 patents in the weights of the fragmentation measure. The problem is especially severe for cases litigated during 1975-78, where most citations refer to patents before 1975, so we use only disputes litigated from 1979-2000. The empirical results using this measure are very similar to those in the baseline specification reported in the text.

Seventh, as we discussed in Section 3, there is a potential truncation problem for cases not terminated before 2000. To address this concern we re-estimate our baseline regression using only cases filed before 1994 (fewer than 4 percent of cases last more than 5 years). This reduces the sample by 24.2 percent. Nonetheless, the results from this restricted sample are very similar to those for the full sample (not reported).

Lastly, we consider the potential endogeneity of the fragmentation measure which might partially account for the negative relationship between fragmentation and settlement duration which we observe. There may be unobserved characteristics of disputes – in particular, transactional and technological complexity – that affect both the ability of firms to negotiate technology transfer agreements and the concentration of ownership of patent rights. When these factors are important, firms may choose to integrate into complementary technology areas in order to internalize these difficult transactions. In this case, fields with less concentrated ownership (i.e. with lower transaction costs) would exhibit shorter settlement duration. It is difficult to think of suitable instrumental variables for fragmentation, so we address this concern in a different way. If fragmentation is simply a reflection of transactional complexity that varies across technology fields, we would expect the coefficient on fragmentation to be smaller (in absolute value) when we conduct the analysis at a more detailed level of technology fields. We check this in column (6), where we replace the eight technology field dummies with the 36 two-digit categories defined by Hall, Jaffe and Trajtenberg (2001). The results are nearly identical to those in our baseline regression.

4.4 Selection Bias

There are two potential sources of selection bias. One involves selection of disputes into court suits. In a more complete specification of the settlement process, there are two equations: first, a litigation equation that determines which disputes get to the stage of court suit, and second, a settlement duration equation that determines how long disputes last after the suit. The two papers on patent litigation by Lanjouw and Schankerman (2001, 2004) look carefully at the first of these equations. In our paper, we focus exclusively on the second stage. It is important to recognize that the bargaining process has both a pre- and post-suit dimension. Reaching the stage of court suit means that the dispute was not settled after it arose (or was discovered by the patentee). It is extremely likely that any factor which influences settlement duration after the suit also affects pre-suit settlement duration (i.e. the probability of litigation). This makes it very difficult to think of suitable instruments for the first-stage (litigation) equation.

What is the likely direction of bias? Any *unobservable* heterogeneity – e.g. complexity of the dispute – that appears in the selection equation should also appear in the settlement equation, so we expect the error terms in the two equations to be positively correlated, say $\sigma_{12} > 0$. But this by itself does not imply that there is a positive bias in the estimated coefficients in the settlement duration equation. The Heckman selection correction involves including the inverse Mills ratio in the regression, with the sign of its coefficient being the same as σ_{12}. Thus the selection model implies that the direction of bias will depend on the sample covariance between the inverse Mills ratio and the exogenous variables in the settlement duration equation, and in general this covariance cannot be signed *a priori.*

While the direction of bias in ambiguous in general, simple economic intuition can offer some guidance as to likely bias. First, we expect that the increased legal certainty associated with CAFC facilitated pre-suit settlement of disputes, leaving only the more complex cases to be litigated. This selection implies that the cases we observe after the introduction of CAFC will tend to be those with longer dispute duration. On this account we will underestimate the true (negative) impact of CAFC on settlement delay. Second, we expect that the bias in the fragmentation coefficient to depend on how dispute complexity is correlated with fragmentation. If fragmentation facilitates pre-suit settlement (because negotiation value is lower), then only the more complex cases will be litigated and thus we will underestimate the true (negative) impact of fragmentation on settlement delay. While we cannot rule out other mechanisms that might cut the other way, we think that the downward biases discussed above are the most plausible outcomes.

Unfortunately, we cannot properly implement the Heckman two-stage selection correction with the available data. The reason is that, as we pointed out, we expect the same variables to affect the probability of litigation and settlement duration, including fragmentation and the CAFC dummy. Even if we were willing to identify only off of functional form (exploiting the non-linearity of the first stage regression), we cannot compute the fragmentation measure for non-litigated patents because it is an infringer-specific measure and there is no infringer for those patents. We also cannot use the CAFC dummy for non-litigated patents in a selection equation because we cannot date a non-litigated dispute (i.e. a patent granted in year t can be litigated any time after t).[31]

The other source of selection bias involves the matching of infringer names in the court data with assignee names in the patent dataset. We were able to match for 5,131 out of 9,219 infringement cases (Section 2 for details). Selection bias could arise in this process, particularly as matching was harder for small infringers. To study this, we estimated a Probit equation to identify the differences between cases we could match and those where we could not, including a the following characteristics: value, complementarity, CAFC, patentee portfolio size, technology fields and court dummies. The probability of matching is significantly related (positively) only to the patentee portfolio size and patent value (not reported, for brevity). We estimated a two-stage Heckman selection model, again identified only from the non-linearity of the first stage regression.[32] The estimated marginal effects of the settlement duration equation are very similar to the estimates of the baseline model (the only material difference is that the marginal effect of patent value is higher after the correction).

5 Fragmentation and Total Settlement Delay

We have shown that fragmentation of patent rights reduces the settlement delay per dispute. In this section we study how fragmentation affects total negotiation delay for a technology user litigating with n different patentees. In our set-up patents are symmetrical in importance and each court focuses on one infringement only. In addition, because damages are independently distributed and determined according to the unjust enrichment doctrine, court decisions will not be affected by the outcome of previous litigations or by the expected outcome of future disputes. These assumptions imply that each settlement negotiation will have an expected length equal to $E(t^*)$ and allow us to simplify the exposition avoiding problems of sequential

[31]Nonetheless, we estimated a Heckman selection correction using the variables in the baseline settlement duration model that do not involve the infringer's identity (complementarity, patent value, technology field dummies, and we also tried the patent portfolio size for the patentee). In doing this, we use a linear specification of the settlement duration equation (to avoid serious computational complexities if we were to use a selection model in a hazard function framework). The selection adjustment does not materially change any of our basic results.

[32]Also in this case we use a linear specification of the settlement duration equation.

common-agency.

To compute total negotiation time, denoted by T, we need assumptions on the timing of negotiations. If all n negotiations are conducted simultaneously, the expected total bargaining delay is $E(t^*)$. At the other extreme, the upper bound in total negotiation time is reached when the downstream user negotiates sequentially with each patentee, in which case the expected total duration is $T = nE(t^*)$.[33] We focus on this case, which represents the maximum delay in technology diffusion predicted by our model.

The impact of fragmentation on total negotiation time is

$$\frac{\partial E(T)}{\partial n} = E(t^*) + \frac{\partial E(t^*)}{\partial n} n \tag{10}$$

This equation points to a trade-off that has been overlooked by previous literature on patent thickets. Ownership fragmentation affects total negotiation time through two channels. The first (positive) term of (10) is the *thicket effect.* Fragmentation extends total negotiation time because it increases the number of negotiations in which the infringer has to engage. The second (negative) term of (10) is the *negotiation value effect.* Fragmentation reduces the value at stake in each negotiation and thus the settlement delay per dispute.

These two effects help reconcile the two opposing views on patent thickets in the recent economic and legal literature – the pro-diffusion view of Licthman (2006) and the anti-commons view of Heller and Eisenberg (1998) and Shapiro (2001). Consider the case where θ is arbitrarily close to zero, so the required patents are almost perfect complements. In this setting the reduction in negotiation time per dispute due to fragmentation, $\partial E(t^*)/\partial n$, is close to zero and the thicket effect dominates the value effect. This result is consistent with the 'anti-commons' view: thickets powerfully increase transaction costs and reduce the speed of technology diffusion. Conversely, Licthman's conjecture holds when θ is arbitrarily close to $n/(n-1)$, so patents are almost perfect substitutes. In this case, the negotiation value per dispute, and thus the settlement time $E(t^*)$, are arbitrarily small. Then the value effect dominates the thicket effect, and total delay is reduced.

[33] This is an upper bound because, following Lerner and Tirole (2004), we assumed that each patent is owned by a different patentee. An intermediate setting would be the case in which the n patents are equally split among k patentees. In this case if the alleged infringer approaches sequentially the k patentees but negotiates simultaneously (and independently) for each subset of patents, the expected delay will be equal to $kE(t^*)$.

Formula (10) implies that fragmentation reduces total negotiation time if $|\varepsilon_{tn}| \equiv \left|\frac{\partial E(t^*)}{\partial n}\frac{n}{E(t^*)}\right| > 1$. Unfortunately, we cannot estimate this elasticity because we do not directly observe n. In the empirical work we used an infringer-specific index of fragmentation, which depends on the total number of patents across different technology classes. For the current calculation, we need to translate the elasticity condition in terms of the fragmentation index.

To simplify, we assume that the user obtains all his inputs from a representative technology class. Then the *Fragmentation1* index is simply $f(N) = 1 - \frac{k(N)}{N} = 1 - C4$ where $k(N)$ denotes the number of patents held by the top four patentees in the class and N the total number of patents in the class. Let ε_{tf} be the elasticity of per-dispute litigation time respect to $f(N)$ and ε_{kN} denote the elasticity of $k(N)$ with respect to N. Using the fact that total negotiation time is $E(T) = nE(t^*(f(N)))$, after some manipulation, we can show that the condition under which an increase in fragmentation will reduce total negotiation time (under sequential negotiations) is

$$|\varepsilon_{tn}| \equiv |\varepsilon_{tf}| \frac{C4}{1-C4}(1-\varepsilon_{kN})\frac{1}{\varepsilon_{nN}} > 1 \tag{11}$$

where ε_{nN} is the elasticity of the number of negotiations, n, with respect to N.[34] Condition (11) essentially requires that the (negative) impact of fragmentation on dispute duration is large enough and that ε_{nN} and ε_{kN} are not too large.[35]

We use our baseline estimates of ε_{tf} for the pre- and post-CAFC sub-periods (-1.7 and -0.4, respectively) and the observed value of $C4$ to evaluate whether condition (11) holds. Since we found no significant differences in the fragmentation coefficient across technology areas (Section 4.2), we use a single value for ε_{tf}. To do this computation, we need to measure the impact of an increase in the number of patents on the portfolios of the top four patentees, ε_{kN}, and on the number of infringer negotiations, ε_{nN}. We compute ε_{kN} as the growth rate of the stock of patents held by the top four patentees divided by the growth rate of the total stock of patents, averaged over the entire sample period for a given technology field. We compute ε_{nN}

[34] In this derivation we think of n, the number of patent holders with whom a technology user needs to bargain, as a (monotonic) function of the total number of patents, N.

[35] The condition is valid provided that $\varepsilon_{kN} \leq 1$. If $\varepsilon_{kN} > 1$, an increase in patenting is associated with an increase in the share of the top four patentees, and thus a reduction in our measure of fragmentation. In this case, settlement delay per dispute would rise, so the increase in patenting would necessarily raise total negotiation delay, $T = nE(t^*)$.

as the average growth rate of the number of patent suits per assignee divided by the growth rate of the patent stock.[36]

Table 6 summarizes the input and results of the calculations.[37] In the regime without CAFC, the condition is satisfied for two technology areas, Other Health and Chemicals. Here the pro-diffusion effect of fragmentation dominates the anti-diffusion effect of the increase in disputes, so total negotiation time declines. In the other technology areas, however, fragmentation is associated with a rise in total negotiation time. The key factor that makes the difference is the extent to which the number of disputes per assignee increased as patenting rose (ε_{nN}). By contrast, in the regime with CAFC the anti-diffusion effect of fragmentation dominates in all technology areas, reflecting the fact that CAFC substantially reduced the pro-diffusion effect of fragmentation.

These calculations are only illustrative and should not be over-interpreted. At the same time, it is worth repeating that this analysis focuses on the most 'pessimistic' case of sequential negotiations. At the other extreme, when negotiations are conducted simultaneously, total negotiation time is simply $E(t^*(n))$ and it immediately follows that fragmentation reduces *total negotiation time* because it reduces delay per dispute. Thus the impact of patent thickets -and the relevance of the Heller and Eisenberg argument- depend crucially on the timing of licensing negotiations, and almost nothing is known about the actual structure of such negotiations.

6 Conclusion

This paper investigates how patent thickets and the formation of the Court of Appeal for the Federal Circuit affect the duration of patent disputes, and thus the speed of technology diffusion through licensing. We develop a model of patent litigation which predicts that settlement agreements are reached more quickly in the presence of fragmented patent rights and when

[36] In doing this, we use the full NBER data set on patenting (not only patents in our litigated sample). We adjust for the substantial under-reporting of patent suits in the court data, using the estimates provided by Lanjouw and Schankerman (2001b), Appendix 1.

[37] It should be noted that over the sample period we observe a decline in the $C4$ measure – hence a rise in fragmentation – in four of the six technology areas: Biotechnology (0.12 to 0.07), Electronics (0.11 to 0.09), Chemicals (0.07 to 0.06), Pharmaceuticals (0.14 to 0.08) and Other Health (from 0.10 to 0.06). In the other two fields – Mechanical and Miscellaneous – fragmentation as we measure it actually declined, so there is no scope for changes in fragmentation to have reduced settlement delay. Thus we do not include these two areas in the table.

there is less uncertainty about court outcomes, as was the case after the introduction of the 'pro-patent' appellate court. The model helps to reconcile two opposite views of patent thickets in recent economic and legal literature: the pro-diffusion view of Licthman (2006) and the anti-commons view of Heller and Eisenberg (1998) and Shapiro (2001). We test the predictions of the model using a dataset that covers nearly all patent suits in U.S. federal district courts during the period 1975-2000.

There are two main empirical findings. First, patent disputes in U.S. district courts are settled more quickly when infringers require access to fragmented external rights, but this effect is much weaker after the introduction of CAFC. Second, the introduction of CAFC is associated with a direct and large reduction on the duration of disputes, which the model attributes to less uncertainty about the outcome if the dispute goes to trial. This finding has implications for current policy debates over the establishment of a European Patent Court with exclusive jurisdiction in cases dealing with infringement and revocation of European patents. Our result suggests that such a centralised court is likely to facilitate transactions in the European market for innovation. In addition, our calculations suggest that fragmentation may have reduced total negotiation delay, and thus sped up rather than retarded technology diffusion, in some technology areas during the period before CAFC.

There are several useful directions for further research. The first is to investigate how bargaining outcomes affect welfare. To do this would require a more 'ambitious' model that incorporates R&D investment decisions, externalities for other innovators, and consumer welfare. A first step in this direction is the work of Noel and Schankerman (2006) that examines how patent thickets affect R&D decisions and market value in the software sector. The second direction is to examine more fully how firm characteristics, including the size and liquidity position of disputants, affects the duration of disputes. Finally, survey evidence on the actual timing and structure of negotiations between downstream users and upstream patent-holders would be extremely useful in assessing the impact of patent thickets on technology diffusion.

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Appendix: Extensions of the Theoretical Model

A.1 Longer Time Horizon and General Payoff Functions

In this Section we introduce both a longer time horizon to the bargaining game and a richer class of payoff functions. Following Spier (1992) we assume that there are T periods of bargaining prior to the court judgment which takes place in period $T+1$. In each period t the patentee makes a settlement offer to the infringer which either accepts or rejects it. If the infringer rejects, the bargaining game continues with the patentee making another settlement offer in the following period. The case proceeds to trial if the litigants cannot agree before time T. If the infringer is found liable, the court will award a judgement $z(n, \theta, V)$ to the patentee. We allow now for a general damage function $z(n, \theta, V)$ that satisfies $\partial z/\partial n \leq 0$ and $\partial z/\partial \theta \leq 0$.[38] As in Spier (1992), we assume a discount factor equal to δ and impose the following technical assumption:

Assumption A1: The defendants' strategies are such that if type p' accepts settlement offer S_t with positive probability, then all types $p'' > p'$ accept S_t with probability 1.

Under Assumption A1, the distribution of infringer types that remains in each period is a truncation of the original uniform distribution. Exploiting these truncated distribution, it is straightforward to compute the probability of settlement for each $t = 1, \ldots, T+1$ and the corresponding expected settlement time $E(t^*)$. Proposition A1 shows that the results of Proposition 1 can be generalized to this new setting.

Proposition A1 *The expected settlement time $E(t^*)$ is decreasing in n and θ.*

P roof. From Spier (1992) we know that the distribution of types remaining at the beginning of period t is uniform on $[0, p_t]$ where $p_1 = 1$ in our model. In addition:

$$\begin{aligned} p_t &= p_1 - \delta^{-T} \sum_{i=1}^{t-1} \delta^i \frac{L}{z(n,\theta,V)} \qquad t = 2, ..., T \qquad (12) \\ p_{T+1} &= p_T - \frac{L}{z(n,\theta,V)}. \end{aligned}$$

[38] For example, an alternative micro-foundation can be obtained building on Schankerman and Scotchmer (2001) which assume that without one patent the commercial product can still be developed and it generates revenue V. In this case the development occurs using a substitute tool that costs $\sigma(n, \theta)$ and the value at stake in the negotiation is $z(n, \theta) = V - (V - \sigma(n, \theta)) = \sigma(n, \theta)$. In this setting the assumptions on the derivatives of z will be satisfied if it is less expensive to find a substitute tool when the technology is fragmented and when the patent has lots of substitutes.

Given these cutoffs, we can express the expected agreement time as:

$$\begin{aligned} E(t^*) &= \sum_{t=1}^{T} t\frac{(p_t - p_{t+1})}{p_1} + (T+1)\frac{p_{T+1}}{p_1} \\ &= \sum_{t=1}^{T+1} \frac{p_t}{p_1} = (T+1) - \frac{L}{z(n,\theta,V)} \sum_{t=1}^{T} \frac{t}{\delta^{t-1}}. \end{aligned}$$

It follows immediately that $\frac{\partial z}{\partial n} \leq 0$ implies $\frac{\partial E(t^*)}{\partial n} \leq 0$, and $\frac{\partial z}{\partial \theta} \leq 0$ implies $\frac{\partial E(t^*)}{\partial \theta} \leq 0$. ■

A.2 Signalling Games

The game presented in Section 2 is a screening game in which the uninformed patentee screens the various types of infringers by making settlement offers. In this section we show that the comparative statics do not change if we convert the framework into a signalling game where the informed party makes the settlement offer. We will consider two different signalling games: one in which the patentee has private information about the probability of winning and makes the settlement offer, and another in which the infringer is the informed player and makes the offer.

Informed Patentee

If the patentee has private information about the probability of winning at the trial his strategy is now a function $S = s(p)$ which specifies a settlement demand for each possible type p. A strategy for the defendant is a function $\rho = d(S)$ which assigns the probability of rejecting the settlement offer S. Because the infringer does not know the winning probability p (he only knows that is uniformly distributed over the interval $[0, 1]$), he must form some beliefs $b(S)$ about p on the basis of the settlement demand S.

Given these beliefs the expected payoff for the infringer when a settlement offer S is made and he rejects it with probability ρ is

$$\pi_i(S, \rho) = \rho\,(V - b(S)z - L_i) + (1 - \rho)(V - S). \tag{13}$$

The expected payoff for the patentee of type p if he demands S to settle and takes as given the strategy $d(S)$ of the defendant, is

$$\pi_p(S, p) = d(S)\,(pz - L_p) + (1 - d(S))S. \tag{14}$$

This signalling game has the same structure as the one studied by Reinganum and Wilde (1986). Following their analysis we define a separating equilibrium as a triple (b^*, s^*, d^*) such that:

1. given the beliefs b^* the probability of rejection policy d^* maximizes the infringer's expected wealth;

2. given d^* the settlement demand policy s^* maximizes the patentee's expected wealth;

3. $b^*(S) \in [0,1]$ for all S with $b^*(s^*(p)) = p$ for all $p \in [0,1]$ (beliefs are correct in equilibrium).

A standard problem with signalling games is the very large number of perfect Bayesian (and sequential) Nash equilibria these games posses. The multiplicity is due to the absence of restrictions on out-of-equilibrium beliefs. To address this issue, a number of refinements have been proposed. Reinganum and Wilde (1986) focus on the unique equilibrium satisfying the 'universal divinity' criterion of Banks and Sobel (1987), requiring the receiver of the signal to believe that an out-of-equilibrium message comes from the sender type that profits most from sending it. This separating equilibrium has the following characteristics in our setup:

$$\begin{aligned}
d^*(S) &= 1 \text{ for } \quad S > z + L_i \\
d^*(S) &= 1 - e^{-\frac{(S-L_i)}{L}} \text{ for } \quad L_i \leq S \leq z + L_i \\
d^*(S) &= 0 \text{ for } \quad L_i > S \\
s^*(p) &= pz + L_i \quad \text{with } p \in [0,1] \\
b^*(S) &= 1 \text{ for } \quad S > z + L_i \\
b^*(S) &= (S - L_i)/z \text{ for } \quad L_i \leq S \leq z + L_i \\
b^*(S) &= 0 \text{ for } \quad L_i > S.
\end{aligned}$$

The intuition for the previous result is the following. First notice that the maximum expenditure that an infringer will sustain at a trial is $z + L_i$, so the infringer will always reject any settlement demand larger than this amount. Moreover, because the infringer maximizes his payoff, the first order condition is

$$\frac{\partial \pi_i}{\partial \rho} = V - b(S)z - L_i - V + S = 0$$

which, because in a separating equilibrium $b^*(s^*(p)) = p$, can be rewritten as

$$s^*(p) = pz + L_i. \tag{15}$$

Similarly, differentiating the expected payoff of the patentee we obtain

$$\frac{\partial \pi_p}{\partial S} = d^{*\prime}(S)(pz - L_p - S) + 1 - d^*(S) = 0. \tag{16}$$

Combining (15) and (16) we obtain the following first order linear difference equation

$$-d^{*\prime}(S)L + 1 - d^*(S) = 0 \tag{17}$$

(where $L = L_i + L_p$) that has a one-parameter family of solutions $d^*(S) = 1 + \lambda e^{-\frac{S}{L}}$. Because $d^*(L_i) = 0$ the probability of equilibrium rejection function becomes

$$d^*(S) = 1 - e^{-\frac{(S-L_i)}{L}}.$$

We compute now the expected length of the litigation game. Because in equilibrium $s^*(p) = pz + L_i$ we have

$$\text{Prob(Litigation}|p) = 1 - e^{-\frac{pz}{L}}.$$

Because p is uniformly distributed over the interval $[0, 1]$, the expected length of a dispute is

$$E(t^*) = \int_0^1 (1 - e^{-\frac{pz}{L}})dp = 1 - \frac{L}{z}(1 - e^{-\frac{z}{L}}). \tag{18}$$

Proposition A2 *The expected settlement time, $E(t^*)$, is decreasing in n and θ.*

P roof. From equation (18) we have that $\partial E(t^*)/\partial z = -\frac{L}{z^2}\left(e^{-\frac{z}{L}} - 1 + \frac{z}{L}e^{-\frac{z}{L}}\right) > 0$. It follows immediately that $\partial E(t^*)/\partial n \leq 0$ and $\partial E(t^*)/\partial \theta \leq 0$. ■

This proposition confirms that the testable hypothesis $H1$ and $H2$ do not depend on the assumption of infringer's private information.

Because $E(t^*)$ is non-increasing in n, it is straightforward to see that introducing CAFC, as modeled in Section 2.4, leads to the result that the expected settlement time is decreasing in α and that $\partial^2 E(t^*)/\partial n \partial \alpha \geq 0$. This shows that hypotheses $H3$ and $H4$ do not depend on the allocation of private information.

Finally, we compute the expected length of a dispute if the likelihood that the patentee will prevail at trial is uniformly distributed over the interval $\left[\frac{1}{2}(1-\lambda), \frac{1}{2}(1+\lambda)\right]$ with $\lambda \in [0,1]$. In this case

$$E(t^*) = \int_{\frac{1}{2}(1-\lambda)}^{\frac{1}{2}(1+\lambda)} (1 - e^{-\frac{pz}{L}})dp = \lambda + \frac{L}{z}e^{-\frac{1}{2}\frac{z}{L}(1+\lambda)} - \frac{L}{z}e^{-\frac{1}{2}\frac{z}{L}(1-\lambda)}. \tag{19}$$

Because formula (19) is increasing in λ, this alternative model is also consistent with testable prediction $H5$.

Infringer Makes the Offer

In the model of Section 2, the patentee made the offer to the infringer. We now show that if the infringer makes the offer the expected settlement delay is equivalent to the one in which the patentee has private information and makes the offer.

In this setting a strategy for the infringer is a function $S = s(p)$ which specifies a settlement demand for each possible type p. A strategy for the patentee is a function $\rho = d(S)$ which assigns the probability of rejecting the settlement offer S. Because the patentee does not know the winning probability p (he only knows that is uniformly distributed over the interval $[0,1]$), he must form some beliefs $b(S)$ about p on the basis of the settlement demand S. Given these beliefs the expected payoff for the patentee when a settlement offer S is made and he rejects it with probability ρ is

$$\pi_p(S,\rho) = \rho\,(b(S)z - L_p) + (1-\rho)S. \tag{20}$$

The expected payoff for the infringer of type p if he demands S to settle and takes as given the strategy $d(S)$ of the patentee is

$$\pi_i(S,p) = d(S)\,(V - pz - L_i) + (1 - d(S))(V - S). \tag{21}$$

Consider the decision of the patentee. He maximizes his payoff and the first order condition is

$$\frac{\partial \pi_p}{\partial \rho} = b(S)z - L_p - S = 0.$$

Since in a separating equilibrium $b^*(s^*(p)) = p$, this can be rewritten as

$$s^*(p) = pz - L_p. \tag{22}$$

Similarly, differentiating the expected payoff of the infringer we obtain

$$\frac{\partial \pi_p}{\partial S} = d^{*\prime}(S)(S - pz - L_i) + 1 - d^*(S) = 0. \tag{23}$$

Combining (22) and (23) we obtain the following first order linear difference equation:

$$-d^{*\prime}(S)L + 1 - d^*(S) = 0. \tag{24}$$

Notice that condition (24) is identical to (17). Because of the equivalence of the two equilibrium conditions, the expected settlement time will be determined by the same formula in the two games, and predictions $H1 - H5$ developed in Section 2 hold in this alternative setting.

A.3 Patentee and Infringer Compete in the Product Market

In this section we extend the game to incorporate competition between the patentee and the infringer. Following Meurer (1989) we assume that a patentee and a competitor negotiate over a settlement of a patent dispute. If the patent is litigated and the infringer is not found liable the two firms become symmetric duopolists and each obtains profits denoted by π^D. Because in this case the two players have access to the same set of patented inputs, it is reasonable to assume that their profits are identical and do not depend on the complementarity and fragmentation of the patents. If the infringer is found liable, profits of the patentee and the infringer are $\pi^P(n,\theta)$ and $\pi^I(n,\theta)$ with $\pi^P(n,\theta) > \pi^D > \pi^I(n,\theta)$. We make the following assumption:

Assumption A2: $\partial\pi^P(n,\theta)/\partial n \leq 0$, $\partial\pi^P(n,\theta)/\partial\theta \leq 0$, $\partial\pi^I(n,\theta)/\partial n \geq 0$ and $\partial\pi^I(n,\theta)/\partial\theta \geq 0$.

Assumption A2 says that the advantage of the patentee over the infringer is smaller when the ownership of the intellectual property is fragmented and when patent complementarity is weak.

In this framework, an infringer of type p will accept a settlement S only if $\pi^D - S \geq p\pi^I(n,\theta) + (1-p)\pi^D - L_i$, so the maximum settlement offer acceptable will be $S = p(\pi^D -$

$\pi^I(n,\theta)) + L_i$. Knowing this the patentee optimization problem becomes

$$\max_p \int_p^1 [p(\pi^D - \pi^I(n,\theta)) + L_i + \pi^D]dy + \int_0^p [y\pi^P(n,\theta) + (1-y)\pi^D - L_p]dy$$

subject to the constraint $p \in [0,1]$. The first integral is the expected settlement value, and the second is expected outcome from litigation net of the patentee's litigation cost. Defining $L \equiv L_i + L_p$, the unconstrained first order condition yields the following optimal cutoff type:

$$E(t^*) = p^* = \frac{\pi^D - \pi^I(n,\theta) - L}{2\pi^D - \pi^P(n,\theta) - \pi^I(n,\theta) + \pi^D - \pi^I(n,\theta)}. \tag{25}$$

Two points should be noted. First, equation (25) identifies the optimal cutoff only if the second order condition of the patentee's maximization problem is satisfied. This condition is satisfied as long as

$$\pi^D > \frac{\pi^P(n,\theta) + 2\pi^I(n,\theta)}{3}. \tag{26}$$

Condition (26) indicates that fragmentation and complementarity can affect settlement timing only if competition is not too intense. If after licensing the two firms compete very aggressively (i.e. (26) is not satisfied), then the patentee will avoid licensing and will never propose an acceptable settlement.[39]

Second, equation (25) implies that we get an internal solution provided $L \leq \overline{L} \equiv \pi^D - \pi^I(n,\theta)$ and $L \geq \underline{L} \equiv \pi^P(n,\theta) + \pi^I(n,\theta) - 2\pi^D$. If legal costs are very large there will always be immediate settlement, and if legal costs are very small parties never settle.

If competition is not too intense (condition (26) holds) and $L \in \left[\underline{L}, \overline{L}\right]$, licensing occurs and the settlement time depends on the level of fragmentation and complementarity. In the next proposition we show that when legal costs exceeds a threshold $\widetilde{L}$ the comparative statics of our baseline model hold.

Proposition A3 *If condition (26) holds and $L \geq L \geq \widetilde{L} \equiv (\pi^P(n,\theta) - \pi^D)/2$ the expected settlement time is decreasing in n and θ.*

P roof. The sign of the derivative of $E(t^*)$ respect to n is equal to the sign of:

$$-\frac{\partial \pi^I(n,\theta)}{\partial n}\left(2\pi^D - \pi^P(n,\theta) - \pi^I(n,\theta) + \pi^D - \pi^I(n,\theta)\right)$$
$$+\left(\frac{\partial \pi^P(n,\theta)}{\partial n} + 2\frac{\partial \pi^I(n,\theta)}{\partial n}\right)\left(\pi^D - \pi^I(n,\theta) - L\right)$$

[39] Implicitly we assume that antitrust authorities prevent parties to use the settlement to enforce the collusive outcome (see Gilbert and Shapiro, 1997).

which is negative as long as

$$-\frac{\partial\pi^I(n,\theta)}{\partial n}\left(2L-\pi^P(n,\theta)+\pi^D\right)+\frac{\partial\pi^P(n,\theta)}{\partial n}\left(\pi^D-\pi^I(n,\theta)-L\right)\leq 0.$$

Since $\partial\pi^P(n,\theta)/\partial n \leq 0$, the second term is negative. Since $\partial\pi^I(n,\theta)/\partial n \geq 0$ the first term is negative as long as $L \geq \widetilde{L}$. The same holds for θ. ■

This proposition shows that the comparative statics still hold with product market competition provided legal costs are not too small. The intuition is that, because $\pi^P(n,\theta)$ declines in n, the patentee has less incentive to litigate and enforce his patent. At the same time, larger n reduces the infringer willingness to pay for a license and this makes litigation more appealing. As long as $L \geq \widetilde{L}$ the first effect dominates and fragmentation reduces settlement delay. If $L < \widetilde{L}$ the impact of the two effects is ambiguous. The next proposition provides a sufficient condition that ensures settlement time decreases with n and θ.

Proposition A4 *If condition (26) holds and* $\underline{L} \leq L < \widetilde{L} \equiv (\pi^P(n,\theta)-\pi^D)/2$ *the expected settlement time may decreases in* n *and* θ *if:*

$$\left|\frac{\partial\pi^I(n,\theta)}{\partial n}\right| \leq \left|\frac{\partial\pi^P(n,\theta)}{\partial n}\right|.$$

P roof. The sign of the derivative of $E(t^*)$ respect to n is equal to the sign of

$$-\frac{\partial\pi^I(n,\theta)}{\partial n}\left(2L-\pi^P(n,\theta)+\pi^D\right)+\frac{\partial\pi^P(n,\theta)}{\partial n}\left(\pi^D-\pi^I(n,\theta)-L\right)\leq 0$$

which holds if

$$\frac{\left|\frac{\partial\pi^I(n,\theta)}{\partial n}\right|}{\left|\frac{\partial\pi^P(n,\theta)}{\partial n}\right|} \leq \frac{\pi^D-\pi^I(n,\theta)-L}{\pi^P(n,\theta)-2L-\pi^D}. \tag{27}$$

■

Notice that $L \geq \underline{L}$ implies that the right-hand side of the inequality is greater than one and gives the sufficient condition. Another implication of the proposition is that, if n (or θ) has a similar impact on patentee and infringer payoff, then all the testable implications in Section 2 are valid with product market competition.

A.4 Endogenous Discovery of Disputes

In Section 2, we assumed that a dispute between a patentee and infringer was exogenous and always reached a court suit. In this appendix we endogenize litigation by extending the model in two ways. First, we endogenize the propensity of disputes to be litigated by introducing a pre-suit settlement stage. Second, we endogenize the propensity of disputes to be discovered assuming that the patentee needs to sustain a cost to identify an infringer in the first place.

To introduce a pre-suit settlement stage, we move from the two-stage game described in Section 2 to a three-stage game. At time $t = 0$ (the 'pre-suit' stage), the patentee makes a take-it-or-leave it settlement offer to the infringer. If he accepts the offer, the game ends. If the offer is rejected, the patentee files the case and makes another offer at $t = 1$. If the second offer is rejected, a trial takes place at $t = 2$. We assume that parties do not sustain a cost in $t = 0$ but that they incur costs L_p and L_i in the other two periods.[40]

Using (12) it is easy to see that the fraction of infringer types settling at $t = 0$ is equal to L/z and that the fraction of those going to trial is $1 - 2L/z$. In the next proposition we show that introducing this pre-suit stage does not affect our main results.

Proposition A5 *The expected settlement time of litigated disputes is non-increasing in n and θ. In the presence of court bias, the duration is decreasing in α and has positive cross-partial derivative in α and n.*

P roof. The expected duration of a filed dispute is equal to

$$E(t-1|t>0) = 0\frac{L/Z}{1-L/z} + 1\frac{1-2L/Z}{1-L/z} = \frac{z-2L}{z-L}$$

which is decreasing in n and θ. With court bias the expected duration becomes

$$E(t^B-1|t>0) = (1-\alpha)\frac{z-2L}{z-L}$$

which is decreasing in α and has positive cross-partial derivative in n and α. ■

Following Crampes and Langinier (2002), we now extend this three period game to endogenize the discovered disputes. To this end we assume that the patentee sustains a cost to identify an infringer. With a monitoring effort expenditure x the patentee identifies the infringer with probability $g(x)$ where $g'(x) > 0$, $g''(x) < 0$, $g(0) = 0$. In addition, we assume that there exists $\overline{x}$ such that $g(\overline{x}) = 1$. If the infringer is identified the game proceeds as described above.

[40] Results are not affected if we allow parties to incur a settlement cost in period zero.

Once the infringer is identified the expected payoff of the patentee is

$$\begin{aligned} E(\pi^P) &= \frac{L}{z}(p^* z + 2L_i) + \frac{L}{z}(p^* z + L_i - L_p) + \frac{p^*}{2} z - 2p^* L_p \\ &= \frac{z^2 - 4zL_p + 2L^2}{2z} \leq z \end{aligned}$$

where p^* is the optimal cutoff type.[41] Thus

$$\frac{\partial E(\pi^P)}{\partial z} = \frac{1}{2} - \left(\frac{L}{z}\right)^2 > 0. \tag{28}$$

Therefore, the problem for the patentee is

$$\max_x g(x) E(\pi^P) - x$$

which has a unique solution x^* such that

$$g'(x^*) = \frac{1}{E(\pi^P)}. \tag{29}$$

Proposition A6 *A dispute between a patentee and an infringer is less likely to be discovered when the infringer requires access to fragmented patent rights and when the patent has more substitutes (i.e., less complementarity).*

P roof. It follows immediately (28) , (29) and the fact that $g''(x) < 0$. ■

The intuition is straightforward: the patentee has less incentive to invest in effort to detect infringements when the value at stake in the negotiation is lower. As in the baseline model in Section 2, this is the case when patent ownership is more fragmented and when there is more substitutability among patents.

After the establishment of CAFC, the expected payoff of the patentee becomes

$$E(\pi^{CAFC}) = (1 - \alpha) E(\pi^P) + \alpha z$$

and thus

$$\frac{\partial E(\pi^{CAFC})}{\partial \alpha} = z - E(\pi^P) \geq 0. \tag{30}$$

[41] This cutoff equals $p^* = 1 - 2L/z$ and is obtained solving:

$$\max_p \int_{p+\frac{L}{z}}^{1} (pz + 2L_i) dy + \int_p^{p+\frac{L}{z}} (pz + L_i - L_p) dy + \int_0^p (yz - 2L_p) dy.$$

Proposition A7 *A dispute between a patentee and an infringer is more likely to be discovered after the establishment of CAFC.*

P roof. It follows immediately from (29), (30) and $g''(x) < 0$. ■

The intuition is that the pro-patent shift associated with CAFC gives the patentee greater incentives to invest in monitoring effort and thus to discover disputes. Note, however, that any discovered dispute will be settled more quickly because CAFC reduced uncertainty in the litigation environment.

Endogenising the discovery of disputes generates additional empirical implications regarding the number of litigated cases. In the discussion that follows, we maintain the assumption that changes in fragmentation, complementarity and CAFC do not affect the underlying population of *potential* disputes. If we remove this assumption results are ambiguous and depend on how we expect the underlying population to change. We believe that focusing on the case of no change in the underlying population is sensible for two reasons. First, it is not clear how fragmentation (or complementarity and CAFC) may alter the number of downstream technology users, so that any assumption on how the population of disputes changes would be ad-hoc. Second, because it not possible to observe the underlying population of disputes, any such assumption would be non-testable.

Because fragmentation reduces the incentives to detect infringements, one implication of our results is that we should observe a smaller number of suits filed per-patent in technology areas where the ownership is fragmented. In principle this implication can be tested empirically. However, we cannot test it using our data because our fragmentation measure is specific to the infringer rather than the patent. In order to test this prediction we would need a measure of fragmentation for a "representative disputant" (see Lanjouw and Schankerman, 2004). While interesting, this task is beyond the scope of this paper.

Finally, this analysis suggests that the introduction of CAFC has two distinct impacts: it increases the number of discovered disputes because of pro-patent bias, but at the same time it facilitates pre- and post-suit settlement of these cases because of the greater certainty in enforcement. Because of these countervailing effects, our model has no empirical prediction about how the number of litigated disputes changes after CAFC. The next proposition summarizes this result.

Proposition A8 *A potential dispute between a patentee and infringer is less likely to be litigated when the infringer requires access to fragmented patent rights and when the patent has more substitutes. The impact of CAFC on the probability of litigation is ambiguous.*

P roof. The probability of litigation is

$$\Pr(Lit) = g(x^*)(1-\alpha)\left(1-\frac{L}{z}\right)$$

which decreases in n and θ. The derivative respect to α is

$$\frac{\partial \Pr(Lit)}{\partial \alpha} = \left[g'(x^*)\frac{\partial x^*}{\partial \alpha}(1-\alpha) - g(x^*)\right]\left(1-\frac{L}{z}\right) \lesseqgtr 0.$$

■

A.5 Order of Negotiations

We now show we lose no generality by focusing the analysis on the last negotiation in the symmetric model, provided certain conditions are met. We also discuss how the predictions are affected if patents are not symmetric.

Consider the simple case in which there are only two patents, A and B, and the infringer litigates first with patentholder A. We start by focusing on the second (and last) negotiation. The infringer will litigate with patentholder B after having negotiated a settlement with patentholder A. It is important to notice that, because of the structure of our game, at this stage the infringer has access to patent A. The reason is that in our game there is always licensing of the innovation – the licensing fee is determined either through settlement or through damages but the technology is transferred in both cases.[42] This means that when the infringer negotiates with B, he will also obtain access to the patent and the game will only determine the expenditure sustained. Denote the expected value of this expenditure as $E(f^B)$.

Consider the negotiation with patentholder A. If the infringer receives an offer S, he knows that accepting it he will obtain the technology at a cost of $S + E(f^B)$. Rejecting it, the two patents will be obtained at a cost equal to $pz + L_i + E(f^B)$. Thus a defendant of type p will accept a settlement S only if $S \leq pz_i + L_i$, i.e. $p \geq (S - L_i)/z$. This condition is identical

[42] Because in the baseline model the patentee and the infringer do not compete in the product market, the patentee has always an incentive to license the technology.

to the one derived in Section 2 for the last patentholder, so our earlier comparative statics are unaffected.

However, there are two important caveats to this result. First, all the n negotiations look identical as long as the court assesses each case in isolation and damages are awarded following the Unjust Enrichment doctrine. But courts may take into account damages awarded to other plaintiffs if the infringer has limited assets (as in Spier, 2002). For example, courts may choose not to award total damages exceeding V. In this instance, damages are

$$z = \min\left\{V - V\frac{(n-1)}{n}\theta, \frac{V}{n}\right\}$$

so expected settlement time is always decreasing in fragmentation, but independent of complementarity when $\theta \leq 1$.[43],[44]

Second, the result depends on the crucial feature of the model that there is always licensing both on and off the equilibrium path. In our model the patentee never leaves the negotiating table without licensing the technology. This assumption is consistent with previous models in the literature (Bebchuk, 1984; Reinganum and Wilde, 1986; Spier, 1992), but it is a limitation that future research needs to address.

In appendix A.3, we assumed that competition between infringer and patentee was not so intense as to render licensing unattractive to the patentee (condition (26). If this condition is not satisfied, it may be profitable for the patentee to refuse to license his patent. If we allow some of the patentees not to license their patents, some of the comparative statics results in our model will be no longer be valid. To see this, assume that at the last negotiation the infringer has obtained access only to $n-2$ patents (i.e. one patentee has refused to license). In this case the value at stake in the last negotiation will be

$$V\frac{(n-1)}{n}\theta - V\frac{(n-2)}{n}\theta = \frac{V\theta}{n}$$

[43] The fact that, when $\theta \leq 1$ each patentee obtains V/n, is consistent with the *pro-rata* share of the defendant's assets (Spier, 2002).

[44] Alternatively, if the infringer has total assets $M \leq nz$ and courts consider each dispute in isolation, then the infringer will be able to pay damages z only for the first $\widehat{n}$ disputes, where $\widehat{n}$ is the largest integer such that $\widehat{n} \leq M/z$. For these disputes settlement time is decreasing in n and θ. For dispute $\widehat{n}+1$ damages are equal to $M - \widehat{n}z$ and settlement time *increases* in θ and n. For the remaining $n - \widehat{n} - 1$ disputes damages are zero. Therefore a budget constraint may reverse the comparative statics but for at most one dispute.

which is decreasing in n but increasing in θ. To see the intuition, compare the case in which patents are perfect complements, $\theta = 0$, with the case in which the value of the technology is equally split, $\theta = 1$. In the first case the last patent will be worth zero because one of the patent is not accessible, in the second case the patent is worth V/n. This example suggests that when the option of not licensing the technology is available to the patentee, the comparative statics on complementarity may not hold.

A final remark concerns the assumption that patents are symmetrical in importance. Relaxing this assumption implies having a different 'negotiation value' for each patent. Moreover, each patent will have its own degree of complementarity, θ_i, with the other $n-1$ patents. With asymmetry, the negotiation value for patent i is

$$z_i(n, \theta_i, V) = V - V_{-i}(n, \theta_i, V)$$

where $V_{-i}(n, \theta_i, V)$ is the revenue obtained without patent i. Predictions $H1 - H5$ developed in Section 2 continue to hold as long as $V_{-i}(n, \theta_i, V)$ increases in n and θ_i for all i.[45]

A.6 Generalization of the CAFC Effect

In the paper we model the impact of CAFC is a highly stylized way. In this section we present a more general formulation. Following Rothschild and Stiglitz (1970), we use a more general family of distribution functions to investigate the impact of a first order stochastic dominance shift in the distribution of the probability of the patentee prevailing at trial: $G(p, m) = p^m$ with $m \geq 1$ and $0 \leq p \leq 1$. For each m the mean of $G(p, m)$ is $m(m+1)^{-1}$ and the variance is $m(m+2)^{-1}(m+1)^{-2}$. Distributions with larger values of m have higher mean and lower variance, and first-order stochastically dominate those with lower values of m.

As in the case of the uniform distribution, fragmentation (large n) reduces bargaining delay whereas complementarity (low θ) increases the expected settlement time per dispute.[46]

Proposition A9 *The expected settlement time, $E(t^*)$, is non-increasing in n and θ.*

[45] When the negotiation values are asymmetric, the expected settlement times differ across patents, and total negotiation time is given by $\sum_{i=1}^{n} E(t_i^*(n, \theta_i, V))$. Even in this case there is a trade-off between *thicket effect* and *negotiation value effect,* but it is not possible to use ε_{tn} to obtain a condition for a reduction in total negotiation time, as in Section 5.

[46] The comparative statics in fragmentation and complementarity are valid for all distribution functions, $G(p)$, having strictly increasing hazard rate.

P roof. The first order condition in the baseline model becomes:

$$\frac{mp^{m-1}}{1-p^m} = \frac{z(n, \theta, V)}{L}. \tag{31}$$

For each m (31) has a unique solution that we denote $p(m)$ with corresponding expected settlement time $E(t^*) = G(p(m), m)$. Because the left hand side of the first order condition is increasing in p ,we have $\dfrac{dp}{dz} > 0$. In addition, because $\dfrac{dz}{dn} \leq 0$ it is easy to see that

$$\frac{dE(t^*)}{dn} = \frac{dG}{dp}\frac{dp}{dz}\frac{dz}{dn} \leq 0.$$

Similarly because $\dfrac{dz}{d\theta} \leq 0$ it follows that $E(t^*)$ is non-increasing in θ. ■

In Section 2.4 the impact of CAFC was modeled as a shift in the distribution of p, with a fraction of courts awarding damages with probability one. Exploiting the class of distribution functions $G(p, m)$, we can study the impact of CAFC by considering more general first order stochastic dominance shifts. Specifically, we model CAFC as an increase in m leading to a new distribution with higher mean (pro-patent bias) and lower variance (greater predictability). The next proposition shows that if legal costs are not too large an increase in m reduces expected settlement time.

Proposition A10 *If* $\dfrac{z}{L} > \dfrac{1}{1-e^{-1}} \simeq 1.582$ *an increase in m leads to a reduction in expected settlement time.*

P roof. Notice that $\dfrac{dE(t^*)}{dm} = \dfrac{\partial G}{\partial m} + \dfrac{\partial G}{\partial p}\dfrac{dp}{dm}$. By totally differentiating the first order condition we get

$$\frac{dp}{dm} = -\frac{p^{m-1} + mp^{m-1}\log p + \frac{z}{L}p^m \log p}{m(m-1)p^{m-2} + \frac{z}{L}mp^{m-1}}$$

which implies

$$\frac{dE(t^*)}{dm} = -\frac{p^{m-1}\left(1+\log p\right)}{\Delta} \tag{32}$$

where $\Delta = \dfrac{m-1}{p} + \dfrac{z}{L}$. Notice that (32) is negative as long as $\log p > -1$ that requires $p(m) > 1/e$. We will now show that $p(m) \geq 1/e$ implies $p(m') \geq 1/e$ for each $m' \geq m$. To see this notice that the left hand side of the first order condition is increasing in p. Therefore $p(m) \geq 1/e$ implies that:

$$\phi(m) \equiv \frac{m(\frac{1}{e})^{m-1}}{1-\left(\frac{1}{e}\right)^m} \leq \frac{z}{L}.$$

Because $\phi'(m) < 0$ it follows that $\phi(m') < z/L$ and $p(m') \geq 1/e$. This result implies that whenever $p(1) \geq 1/e$ then $p(m) \geq 1/e$ for all $m > 1$. Finally notice that $p(1) = 1 - \dfrac{L}{z}$. Therefore if $\dfrac{z}{L} \geq \dfrac{1}{1-e^{-1}}$ then $p(1) \geq 1/e$, $p(m) \geq 1/e$ for all $m > 1$ and $\dfrac{dE(t^*)}{dm} < 0$. ■

The previous proposition shows that CAFC reduces settlement time if the ratio between legal fees and size of the case is not too large. This generalization also reveals that CAFC has two opposite effects on litigants' incentive to settle. On one hand, it reduces uncertainty (variance) of outcomes and this facilitates settlement agreement. However, it also raises the expected damages and this increases the appeal of litigation. Thus disputes that were too expensive to litigate before CAFC may become profitable to do so after CAFC, and this explains why a condition on z/L is required. The same proposition also shows that the reduction in settlement time is larger for circuits where court decisions have larger variance. It is these circuits for which CAFC represents a larger increase in m.

Finally, the following proposition shows that in this generalized setting the interplay of CAFC and fragmentation is ambiguous, without further restrictions.

Proposition A11 The sign of $\dfrac{d^2E(t^*)}{dndm}$ *can be either positive or negative.*

P roof. $E(t^*) = G(p(m), m)$ implies that:

$$\frac{d^2E(t^*)}{dzdm} = \frac{dg(p)}{dm}\frac{dp}{dz} + \frac{dg(p)}{dp}\frac{dp}{dz}\frac{dp}{dm} + g(p)\frac{d^2p}{dzdm}.$$

Using

$$\frac{dp}{dz} = \frac{1}{z\Delta} > 0$$

$$\frac{dp}{dm} = -\frac{1 + \log p\left(m + \frac{z}{L}p\right)}{m\Delta} \lesseqgtr 0$$

and

$$\frac{dg(p)}{dm} = p^{m-1}\left(1 + m\log(p)\right) \lesseqgtr 0$$

it is easy to see that the sign of the cross-derivative $\dfrac{d^2E(t^*)}{dndm}$ is ambiguous without further restrictions. ■

Figure 1. Distribution of Dispute Duration (in Months)

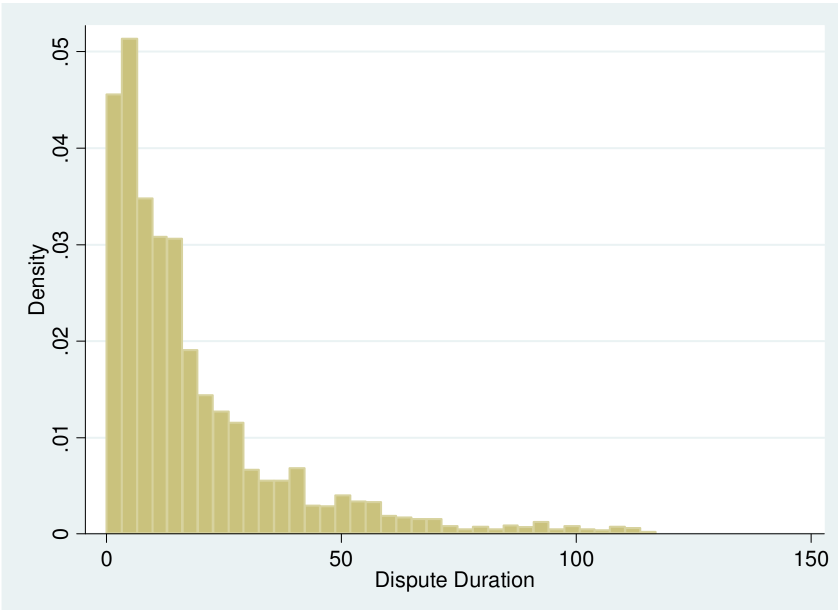
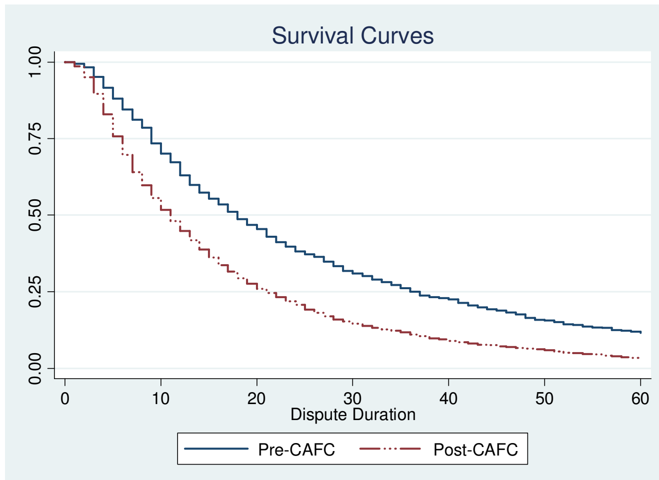
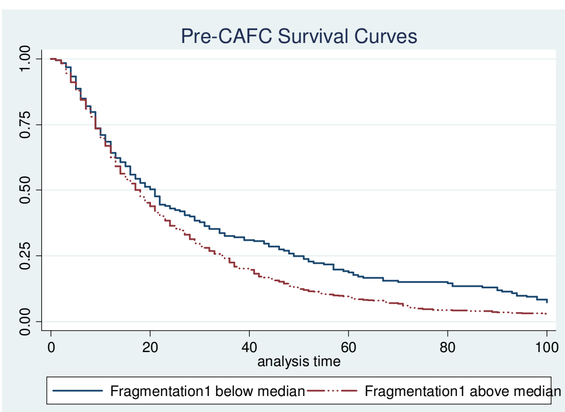


Figure 2. Distribution of Dispute Duration: Impact of CAFC and Fragmentation





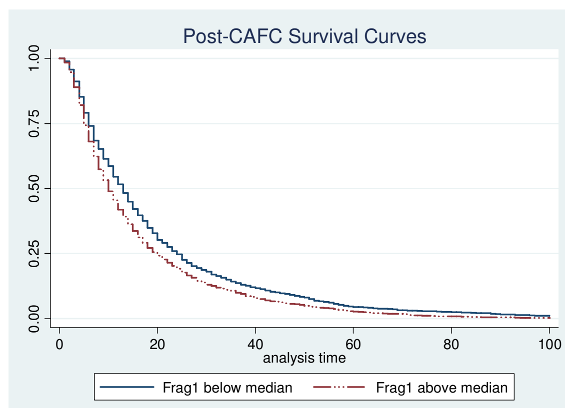


Figure 3. Estimates of Year Effects from Hazard Model of Dispute Duration

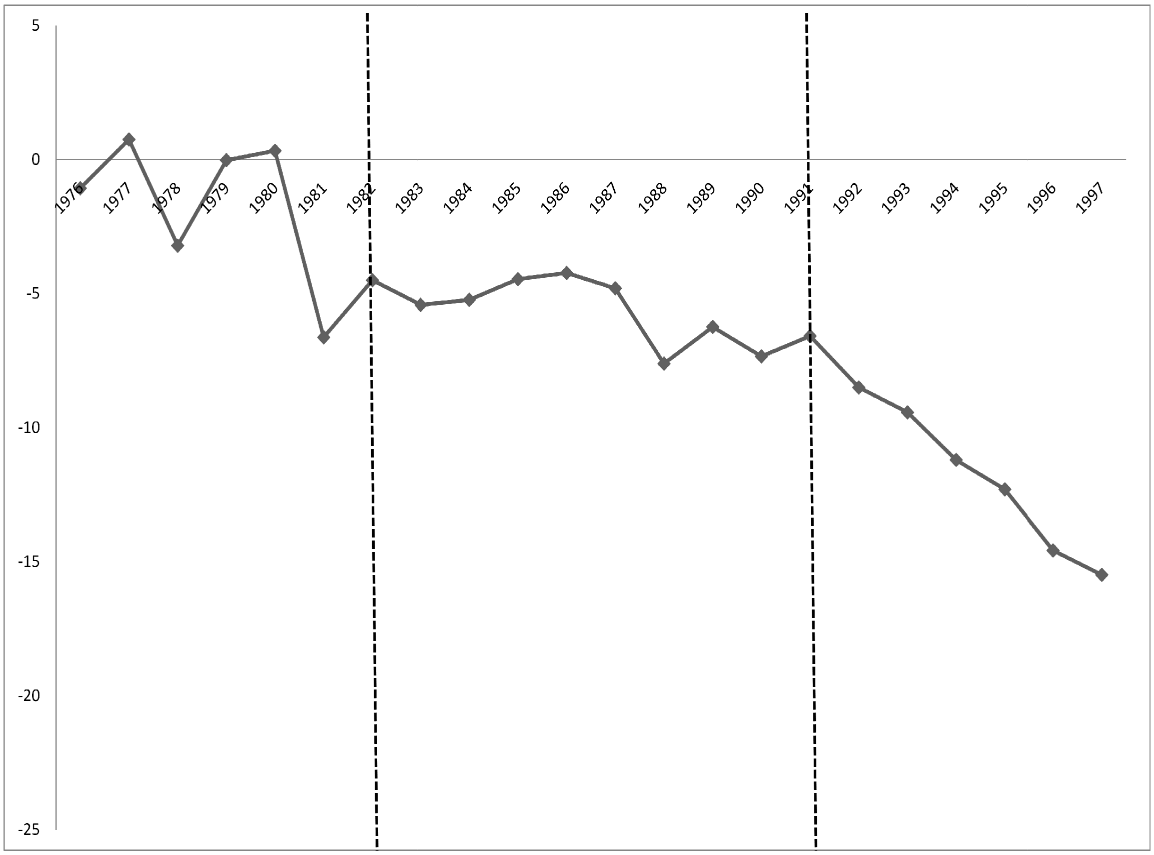


Table 1. Descriptive Statistics

	Mean	Median	Std. Dev.	Min	Max
Dispute Duration (Months)	18.60	12	20.48	0	172
Fragmentation1	0.89	0.91	0.07	0.45	0.99
Fragmentation2	0.95	0.98	0.11	0	1
Complementarity x10^3	0.27	0.01	3.52	0	110.32
Value	18.80	11	25.29	0	327
Age of Patent	7.76	6	5.37	0	20

DISPUTE DURATION: months between case filing date and case termination date; FRAGMENTATION1: 1-weighted average of share of top four patentees in cited classes (see Section 3 for details); FRAGMENTATION2: 1-Herfindal index of entities cited (see Section 3 for details); COMPLEMENTARITY: 1000 x ratio of non self-citations received by the litigated patent to non-self citations of patents in the same technology field; VALUE: number of citations received by litigated patent.

Table 2. Fragmentation, Complementarity and Dispute Duration

	Fragmentation1 < 50th Percentile	Fragmentation1 > 50th Percentile
Dispute Duration	**Mean**	**Mean**
Entire Period (1975-2000)	19.6	17.6
Before CAFC (1975-81)	33.0	27.7
After CAFC (1982-2000)	18.3	16.4
	Complementarity < 50th Percentile	**Complementarity > 50th Percentile**
Dispute Duration	**Mean**	**Mean**
Entire Period (1975-2000)	15.9	23.1
Before CAFC (1975-81)	26.0	32.2
After CAFC (1982-2000)	15.2	21.2

DISPUTE DURATION: months between case filing date and case termination date; FRAGMENTATION1: 1-weighted average of share of top four patentees in cited classes (see Section 3 for details); COMPLEMENTARITY: 1000 x ratio of non self-citations received by the litigated patent to non-self citations of patents in the same technology field.

Table 3. Impact of CAFC on Frequency of Settlement before Pre-Trial Hearing and District Court Adjudications

	Percent Cases Settled before Pre-Trial Hearing		Percent Cases with District Court Decision	
	Before CAFC	After CAFC	Before CAFC	After CAFC
Entire Sample	61.99	80.36	17.19	5.95
Drugs	77.78	71.43	22.22	5.59
Other Health	44.44	74.18	25.93	10.33
Chemicals	60.92	76.12	19.54	5.75
Electronics	67.86	80.78	13.10	3.55
Computers	-	86.96	0.00	0.00
Mechanical	58.28	77.47	20.53	6.24
Biotech	33.33	88.46	33.33	3.85
Others	70.89	78.16	6.33	6.77

Table 4. Baseline Specification - Dependent Variable: Dispute Duration

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coefficient	**Marg. Effect**	**Coefficient**	**Marg. Effect**	**Coefficient**	**Marg. Effect**	**Coefficient**	**Marg. Effect**	**Coefficient**	**Marg. Effect**	**Coefficient**	**Marg. Effect**
Fragmentation1	0.556***	-10.336	0.719***	-13.366	0.567***	-10.601	1.845***	-55.368	1.606***	-48.196	1.460**	-43.815
	(0.179)		(0.181)		(0.192)		(0.628)		(0.598)		(0.607)	
Complementarity x 10^5	-1.161***	21.582	-1.050***	19.519	-0.922***	17.140	-0.887***	16.489	-0.904***	16.805	-0.934***	17.363
	(0.102)		(0.127)		(0.114)		(0.108)		(0.115)		(0.098)	
CAFC	0.293***	-6.008	0.297***	-6.001	0.268***	-5.293	1.563***	-50.714	1.281**	-43.150	1.278**	-41.266
	(0.051)		(0.049)		(0.049)		(0.588)		(0.564)		(0.572)	
CAFC x Fragmentation1							-1.432**	48.207	-1.199*	41.139	-1.188*	39.099
							(0.647)		(0.619)		(0.628)	
High Variance											-0.169*	3.771
											(0.096)	
CAFC x High Variance									0.223**	-4.716	0.175*	-3.825
									(0.101)		(0.101)	
Value x 10^2					-0.165***	3.067	-0.174***	3.235	-0.177***	3.291	-0.172***	3.197
					(0.047)		(0.047)		(0.047)		(0.048)	
Duplicates					-0.556***	12.910	-0.557***	12.933	-0.563***	13.105	-0.586***	14.006
					(0.078)		(0.078)		(0.077)		(0.069)	
Missing					0.062**	-1.093	0.064**	-1.125	0.064**	-1.141	0.060**	-1.081
					(0.028)		(0.028)		(0.028)		(0.029)	
Tech Field Dummies			YES***		YES*		YES*		YES*	YES*	YES*	
District Court Dummies			YES***		YES***		YES***		YES***	YES***	NO	
Year Dummies (1992-2000)	YES***		YES***		YES***		YES***		YES***	YES***	YES***	
Observations	4489		4489		4489		4489		4489	4489	4489	

*NOTES: Robust standard errors are reported in parentheses. Statistical significance: *10%, **5%, *** 1%. Coefficients, standard errors and marginal effects for complementarity and value are multiplied by 100. DISPUTE DURATION: months between case filing date and case termination date; FRAGMENTATION1: 1-weighted average of share of top four patentees in cited classes (see Section 3 for details); COMPLEMENTARITY: 1000 x ratio of non self-citations received by the litigated patent to non-self citations of patents in the same technology field; CAFC= dummy for cases litigated after 1982; HIGH VARIANCE= dummy for 3 circuits with highest variance in outcome; VALUE=number of citations received by litigated patent; DUPLICATES=dummy for cases involving the same patentee, infringer and patent in the same year; MISSING= dummy for infringers without patents; TECH FIELD DUMMIES= dummies for 8 technology areas; DISTRICT COURT DUMMIES= dummies for 89 district courts; YEAR DUMMIES= dummies for year of litigations 1992-2000. Coefficients are from proportional hazard regressions.*

Table 5. Extensions and Robustness - Dependent Variable: Dispute Duration

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coefficient	Marg. Effect	Coefficient	Marg. Effect	Coefficient	Marg. Effect	Coefficient	Marg. Effect	Coefficient	Marg. Effect	Coefficient	Marg. Effect
Fragmentation1	1.900*** (0.628)	-57.019	1.814*** (0.630)	-54.438	1.791*** (0.625)	-53.748	1.833*** (0.628)	-55.001			1.746*** (0.613)	-52.397
Fragmentation2									0.539** (0.251)	-16.715		
Complementarity x 10^5	-1.181*** (0.199)	21.955	-0.885*** (0.109)	16.452	-1.136*** (0.157)	21.119	-0.876*** (0.106)	16.285	-0.917*** (0.109)	17.047	-0.861*** (0.162)	16.006
CAFC	1.603*** (0.587)	-52.159	1.544*** (0.590)	-50.021	1.530*** (0.585)	-49.656	1.615*** (0.588)	-50.043	0.882*** (0.263)	-25.501	1.494*** (0.570)	-47.223
CAFC x Fragmentation1	-1.491** (0.647)	49.927	-1.411** (0.649)	47.450	-1.399** (0.644)	46.951	-1.455** (0.647)	48.446			-1.340** (0.629)	45.397
CAFC x Fragmentation2									-0.649** (0.275)	18.622		
Value x 10^2	-0.294*** (0.084)	5.645	-0.175*** (0.049)	3.253	-0.168*** (0.047)	3.123	-0.180*** (0.048)	3.346	-0.169*** (0.047)	3.141	-0.195*** (0.048)	3. 625
Value*Age x 10^2	0.015** (0.009)	-0.309										
Serial Patentees			-0.200* (0.119)	3.856								
Serial Infringers			0.214* (0.122)	-3.459								
Large Portfolios					0.289** (0.139)	-4.451						
Small Portfolios					0.076** (0.033)	-1.329						
Caseload x 10^2							-0.038** (0.015)	0.706				
Detailed Field dummies	NO		NO		NO		NO		NO		YES***	
Observations	4489		4489		4489		4446		4489		4489	

*NOTES: Robust standard errors are reported in parentheses. Additional controls (not reported) are: missing, duplicates, tech field dummies, court dummies and year dummies for the period 92-00. Statistical significance: *10%, **5%, *** 1%. Coefficients, standard errors and marginal effects for complementarity and value are multiplied by 100. DISPUTE DURATION: months between case filing date and case termination date; FRAGMENTATION1: 1-weighted average of share of top four patentees in cited classes (see Section 3 for details); FRAGMENTATION2: 1-Herfindal index of entities cited (see Section 3 for details); COMPLEMENTARITY: 1000 x ratio of non self-citations received by the litigated patent to non-self citations of patents in the same technology field; CAFC= dummy for cases litigated after 1982; VALUE=number of citations received by litigated patent; AGE= years between grant date and case filing date; SERIAL PATENTEES: dummy for top 1 percent of serial litigants among patentees; SERIAL INFRINGERS: dummy for top 1 percent of serial litigants among infringers; LARGE PORTFOLIOS: dummy for disputes for which both litigants have more than 1,000 patents; SMALL PORTFOLIOS: dummy for disputes for which both litigants have less than 5 patents; CASELOAD= annual ratio of number of cases filed to number of judges in district court; DETAILED FIELD DUMMIES: dummies for 36 technology categories. Coefficients are from proportional hazard regressions.*

Table 6. Impact of Fragmentation on Total Negotiation Time

	e_{nN}	e_{kN}	C4	e_{tn}	
				Without CAFC	**With CAFC**
DRUGS	0.29	0.30	0.10	-0.46	-0.11
OTHER HEALTH	0.05	0.45	0.07	-1.41	-0.33
CHEMICALS	0.05	0.15	0.06	-1.84	-0.43
BIOTECH	0.13	0.28	0.08	-0.82	-0.19
ELECTRONICS	0.26	0.14	0.10	-0.53	-0.14

Notation: e_{nN} = elasticity of negotiations respect to patents granted, e_{kN} = elasticity of the size of four largest portfolios respect to patents granted, C4 = average share of top patentees in the period, e_{tn} = elasticity of negotiation time respect to number of negotiations (see Section 5 for details).