Broad Cross-License Agreements and Persuasive Patent Litigation: Theory and Evidence from the Semiconductor Industry

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Abstract

In many industries broad cross-license agreements are considered a useful method to obtain freedom to operate and to avoid patent litigation. In this paper I study the previously neglected dynamic trade-off between litigating and cross-licensing that firms face to protect their intellectual property. I present a model of bargaining with learning in which firms' decisions to litigate or crosslicense depend on their investments in technology specific assets. In particular the model predicts that where firms' sunk costs are higher, their incentive to litigate and delay a cross-license agreement is lower. In addition, the bargaining game shows how firms with intermediate values of asset specificity tend to engage in inefficient "persuasive litigation". Using a novel dataset on the US semiconductor industry I obtain empirical results consistent with those suggested by the model. Combining model intuition with some empirical figures, I evaluate possible effects of the currently debated patent litigation reform.

Keywords: cross-license, patent litigation, bargaining, semiconductors.

JEL Classification: 031, 032, C78, L63.

1 Introduction

During the past few years various scholars[1] and industry representatives have drawn attention to specific inefficiencies generated by the patent system in several industries. In particular, Shapiro (2001) has argued that a "patent thicket" has appeared that renders it difficult to commercialize a new technology. In some industries the number of intellectual property rights a firm requires to produce a new product is so large, and their ownership is so dispersed, that it is quite easy to unintentionally infringe on a patent. In this environment there is, therefore, a hold-up problem: when the manufacturer starts selling its product a patentee might show up threatening to shut production down unless it is paid high royalties.

This issue's relevance is indicated by the endogenous reaction taken by firms operating in industries where the thicket is especially severe. In fact, various business arrangements enabling firms to cut through the thicket have appeared. The objective of this paper is to analyze one of these arrangements: broad cross-license agreements.[2]

A cross-license agreement is a contract between two companies that grants each the right to practice the other's patents. In other words it is a bilateral agreement in which two firms choose not to enforce intellectual property rights between them. This paper focuses on broad cross-licensing, i.e. on agreements covering the entire patent portfolios or patents in some extensive technology class.

There are three reasons why these contracts are worth a deep scientific scrutiny. First, the existence of contracts in which firms choose to dispose of intellectual property rights granting them monopoly rents is a puzzle for economists. To understand the reasons behind this puzzling behavior may lead to a better comprehension not only of intellectual property enforcement but also of the more general impact of transaction costs on property rights enforcement.

Second, despite their prevalence, cross-license agreements have so far attracted little empirical and theoretical attention from economists compared to other arrangements used to transfer intellectual property (e.g. patent licensing, patent pools and standard setting). A study of these contracts, that lie in between arm's length contracting (patent licensing) and firms full integration (merger or acquisition), may offer valuable insights into firm choices of organizational structure.

The third motivation is a more practical one. The existence of a patent thicket that raises firms cost of innovation has led various economists to question the patent system as the best incentive scheme (a review of this literature is offered in Gallini and Scotchmer (2002)). From this perspective, when two firms cross-license their patent portfolios, they react extremely against the patent system renouncing completely to enforce their intellectual property rights. Therefore, a better understanding of the reasons leading to cross-licensing and of the characteristics of the firms involved may

[1] Among these Shapiro (2001), Heller and Eiseberg (1998), Barton (2000) and Pooley (2000).

[2] Other possible business arrangements include patent pools. Their relevance and their efficiency properties have been analyzed in Lerner and Tirole (2004) and Lerner et al. (2005) and Choi (2002).

help identifying who suffers most from the inefficiencies of the patent system and may help quantifying this efficiency loss. These insights can be very valuable in evaluating the arguments behind the recent calls for patent system reforms.

To study the determinants of broad cross-license agreements, I focus the analysis on the semiconductor industry. This industry is characterized both by rapid technological change and by cumulative innovation. In fact, during the past four decades, semiconductor technology has registered a continuous and steady progress with the number of transistors in a chip doubling every year since 1965.[3] In addition, because of its complexity, a semiconductor product is likely to be covered by hundreds if not thousands of individual patents related both to the transistors and to the circuit design (Hall and Ziedonis (2001) and Ziedonis (2004)).

Because of these features of the technological setting, a semiconductor firm requires to cut through a patent thicket in order to legally manufacture and sell its products. In fact, as previous studies have already noticed (Grindley and Teece (1997), Hall and Ziedonis (2001) and Ziedonis (2003)), the patent thicket looks extremely severe in this industry making cross-license agreements quite a common practice.

I begin the analysis of cross-license agreements developing a theoretical framework in which two semiconductor firms are involved in a sequence of patent infringements. More specifically, in each period of an infinite horizon bargaining game, one of the two firms is chosen by nature to be a patentee producer facing an infringing action from the other firm.

In the absence of a broad cross-license agreement, firms solve these infringements with costly litigation. In particular, a court will determine whether the defendant is found to have infringed and will issue an injunction forcing the infringer to shut production down if this is the case.

I assume that, when halting production, the infringer sustains a cost that increases with the specificity of its technology assets. This important assumption comes from the empirical observation that the losses due to stopping or varying production processes are more detrimental for firms with large sunk costs (Hall and Ziedonis (2001) and Ziedonis (2004)).

If two firms sign a cross-license agreement, they commit not to litigate present and future infringements and therefore to share duopoly profits. Agreement over a cross-license contract is reached through a bargaining procedure. To study this negotiation problem, I build on the theoretical work of Yildiz (2003, 2004). In particular, I extend his "divide-the-dollar" game developing a framework in which firms bargain over a cross-license agreement and introducing a per-period outside option (the litigation payoff) that firms receive in case of disagreement.

Analyzing the equilibrium of this model, I obtain various testable results. In particular, the most important finding is that both the decision to cross-license and the timing of the agreement depend crucially on firms' investment specificity: the

[3]Recent estimates in the Semiconductor Industry Association 2005 annual report predict that this exponential rate of progress will continue at least until 2020.

larger are firms' sunk costs the sooner a cross-license agreement will be arranged. Specifically, the model predicts that firms with low sunk costs never agree upon a cross-license and that firms with high asset specificity agree at the first infringement. In addition, firms with intermediate levels of investments in specific technology reach a cross-license agreement after some litigation.

There are two trade-offs leading to this sorting. First, all firms face a basic trade-off between cross-licensing and litigating. A cross-license agreement is costly because it reduces each innovation monopoly surplus to a duopoly surplus. Nevertheless, to enforce the monopoly surplus firms have to litigate sustaining a cost that increases with their asset specificity and, if sunk costs are high enough, this loss reduces the litigation surplus below the one they can obtain with a broad cross-license. Therefore, firms with low sunk costs never agree upon a cross-license, as perpetual litigation guarantees them a larger surplus.

The second and more subtle trade-off is faced only by firms for which cross-licensing is efficient and it involves the timing of the agreement. More precisely, each firm has an incentive to litigate and delay the agreement because waiting reduces opponent's optimism and therefore decreases opponent's requested surplus share. However, litigation is costly and its cost increases with firms' investment in sunk technology. As a result, only if sunk costs are not too large the benefit of delay exceeds its cost and firms litigate before signing an agreement.

This result is valuable for two reasons. First, it shows that the effects of the patent thicket, and therefore the incentives to cross-license, are not homogeneous across firms. In fact, because firms with large investment in specific assets suffer most from infringements, they have the greatest incentives to cross-license their intellectual properties.

Second, the model unveils a particular inefficiency that has not been noticed in the previous literature which I am going to label "persuasive litigation". In fact, firms with intermediate levels of sunk costs litigate not because it is efficient for them to do so, but because they want to obtain a better deal in a cross-license agreement. This litigation is inefficient because it reduces the surplus that parties will share. Disentangling this inefficient litigation is valuable for policy analysis. Indeed, I show that it implies that policies leading to an increase in the amount of patent litigation (e.g. a reduction in legal costs or a strengthening of patent rights) have an ambiguous welfare impact.

To test the predictions of the model, I compiled a new dataset based on patent litigation and cross-license agreements that semiconductor firms disclosed in their Security Exchange Commission filings. More specifically, following Hall and Ziedonis (2001), I identified from Compustat a sample of 95 publicly traded U.S. firms whose principal line of business is semiconductor and related devices (SIC 3674), that were active from 1998 to 2003 and that engaged in some patent activity after 1988.

In particular, from firms' SEC filings I collected data both on cross-license agreements and on patent litigation and from the NBER patent data file, I obtained information on firms' patent portfolios. In addition, from Compustat, I collected data on relevant financial variables for the semiconductor firms in the sample. Following Hall and Ziedonis (2001) and Ziedonis (2004), I measure the specificity of firms' technology with firms' capital intensity.

To control for the effects of product market competition and technological similarity, I constructed four different distance measures. First, following Bloom, Schankerman and Van Reenen (2005), I empirically computed firm distances in technology space using information on the distribution of their patenting across technological areas. Second, using information on patent citations, I estimated an index of technological linkages across firms. Finally, collecting data from firm catalogues and firm sales I constructed two measures of firm similarity in the product market space.

Constructing all possible pairings among firms in the sample, I observe that for various pairings there is neither litigation nor cross-licensing. Nevertheless, among pairings disclosing interaction, I notice all three patterns predicted by the theoretical model: some parings resolved their disputes litigating and not cross-licensing, some cross-licensing without litigation and some delaying cross-licensing with a period of patent litigation.

To identify the impact of capital intensity on the choice of dispute resolution technique and to address the concern that the probability of interaction among firms may be non-random, I adopt a two-stage econometric model. First, I analyze what variables determine the probability of observing firm interactions. In the second stage, exploiting these results, I estimate the determinants of the cross-licensing outcome.

The main empirical findings are consistent with the theoretical model and can be summarized as follows. First, interaction among firms is strongly related to their location in the technology space: the probability to observe either patent litigation or cross-license agreements is higher for firms closer in the technology space and this probability increases with firms' patent portfolios. Second, once I correct for the probability of observing interactions, both the sorting between cross-license and litigation and the timing of the agreement depend uniquely on firms' capital intensities. In particular, as the model predicts, I found that where firms' capital intensity is higher their incentive to litigate and delay a cross-license agreement is lower.

After having tested the empirical predictions of the model, I exploit the dataset to conduct a simple policy exercise. More precisely, I study the potential effects of a patent litigation reform as the one recently requested by a coalition of leading technology companies. Because of the skewed capital intensity distribution of semiconductor firms, I find that a reform may induce a substantial reduction in the number of broad cross-license agreements.

This paper is connected to various strands of literature. Grindley and Teece (1997) provide a collection of case studies about cross-licensing in semiconductors and electronics. Most of the insights from their analysis of firms practice are captured in my model and its predictions. More specifically, my theoretical model extends the bargaining game of Yildiz (2003, 2004) introducing a per-period outside option borrowed from patent litigation models as those in Lanjouw and Lerner (1998, 2001) and Marjit and alt.(2001).

A different theoretical analysis of patent cross-licensing is in Fershtman and Kamien (1992). While the goal of their paper is to study how R&D investment may be altered with cross-licensing, the focus of this paper is to analyze how firms choose to resolve their disputes assuming a constant innovation pace.

Empirically, my analysis complements the results obtained by the patent litigation literature (Lanjouw and Schankerman (2001, 2004) and Ziedonis (2003)). In fact, combining patent litigation data with cross-license agreements, I obtain new insights into semiconductor firms' strategic interactions. Moreover my paper complements Siebert and von Graevenitz (2005) empirical analysis of licensing in the semiconductor industry. In their paper they study how technological and product market similarity affect firms incentive to license their intellectual property. In their analysis the authors do not distinguish between broad cross-licensing and simple patent licensing and they drop from their dataset contracts related to patent litigation.

The general model is somewhat involved and so to gain intuition, I introduce in section 2 a simple two period example that highlights the main trade-offs leading to the central result. Section 3 discusses the infinite horizon bargaining model. The dataset and its summary statistics are presented in section 4. Section 5 describes the main results of the econometric analysis and section 6 discusses their policy implication. Section 7 concludes.

2 An Illustrative Example

In this section, I present a simple example that shows how asset specificity may shape firms' incentives to cross-license their intellectual property. Moreover, this example illustrates how firms with low or high levels of sunk costs tend to choose efficiently between litigation and cross-license and how firms with intermediate values of specific technology are inclined to be involved in inefficient litigation.

Consider a two period bargaining game between two semiconductor firms $N = \{1, 2\}$. In each period the two firms are involved in a patent infringement dispute. Each dispute arises because of a period specific innovation embedded in a product that grants a total revenue of V and entails a production cost of F.

In the absence of a cross-license agreement the two firms solve the dispute by litigation incurring a per-firm legal cost of L. I assume that the court will find the disputed patent not infringed in half of the cases. In this event the two firms will share the market and enjoy a duopolistic profit of $V/2 - F$. Conversely, if the patent is found to be infringed then the patentee will enjoy a monopoly profit of $V - F$ and the infringer will have to shut production down. In this case the infringing firm will sustain a cost that varies with its investment in specific technology. More precisely, I indicate this cost as kF where $k \in [0, 1]$ is a parameter capturing the specificity of firm assets. This cost arises because the hold-up problem is more serious for firms with large investments in specific technology that either cannot be used if the production cannot take place, or are costly diverted to other activities. I provide further justifications for this modeling assumption in section 3.3.

In this setting, the patentee expected payoff can be written as:

$$\overline{u} = \frac{1}{2}(V - F) + \frac{1}{2}(\frac{V}{2} - F) - L. \tag{1}$$

Conversely, the expected payoff for the infringer is:

$$\underline{u}(k) = \frac{1}{2}(\frac{V}{2} - F) - \frac{1}{2}kF - L. \tag{2}$$

The two firms bargain upon a cross-license agreement. More specifically, at each period the patentee offers the infringer a cross-license contract. In this contract the two firms commit not to litigate present and future intellectual property disputes. In addition, the agreement specifies a monetary transfer between the two parties.

I assume that firm 1 is the patentee in the first period and that the identity of the second period infringer is stochastic. Each firm has a prior belief about the probability of being the second period patentee: firm 1 believes it will be patentee with probability p_1 and firm 2 believes it will be patentee with probability p_2. This belief structure is assumed to be common knowledge.

I define $p_1 + p_2 = 1 + y$ where $y > 0$ denotes the level of aggregate optimism. Moreover, I assume the following parameter restriction:

$$\frac{V}{2} > F > 4L. \tag{3}$$

Timing is as follows.

Period 1: firm 1 makes a cross-license take it or leave it offer to firm 2. If firm 2 accepts the offer, the game ends and the firms split present and future duopolistic payoffs according to the contract. If firm 2 refuses, the dispute is resolved by litigation.

Period 2: nature recognizes the second period patentee. The chosen firm makes a cross-license take it or leave it offer to the infringer. Litigation occurs in the case of rejection.

I solve the game by backward induction. It is easy to see that a cross-license agreement is possible only if $V - 2F \geq \overline{u} + \underline{u}(k)$ that occurs only if $k \geq 1 - 4L/F \equiv \underline{k}$. In fact, if $k < \underline{k}$ then the payoff that parties obtain litigating exceeds the payoff they can get with a cross-license agreement and therefore they will never cross-license their intellectual property.

If $k \geq \underline{k}$, and there is no agreement in the first period, firm 2 second period payoff is going to be $V - 2F - \underline{u}(k)$ if it makes the offer or $\underline{u}(k)$ if firm 1 is the patentee.[4] Therefore, the first period offer of firm 1 that will make firm 2 indifferent between accepting or rejecting a cross-license is:

[4] The main prediction of the example continues to be valid if I constrain parties to litigate in the second period.

$$
\begin{aligned}
t &= \underline{u}(k) + p_2(V - 2F - \underline{u}(k)) + (1 - p_2)\underline{u}(k) \\
&= 2\underline{u}(k) + p_2(V - 2F - 2\underline{u}(k)).
\end{aligned}
$$

This offer is going to be profitable for firm 1 if and only if:

$$
2(V - 2F) - 2\underline{u}(k) - p_2(V - 2F - 2\underline{u}(k)) \geq \overline{u} + \underline{u}(k) + p_1(V - 2F - 2\underline{u}(k))
$$

or

$$
\begin{aligned}
V - 2F - 2\underline{u}(k) + V - 2F - \overline{u} - \underline{u}(k) &\geq (1 + y)(V - 2F - 2\underline{u}(k)) \\
\frac{V - 2F - \overline{u} - \underline{u}(k)}{V - 2F - 2\underline{u}(k)} &\geq y \\
y(k) \equiv \frac{2L - \frac{F}{2}(1 - k)}{\frac{V}{2} - F(1 - k) + 2L} &\geq y
\end{aligned}
$$

where the formula for $y(k)$ is obtained by replacing the litigation payoffs with their definitions.

The result obtained shows that firms are going to delay the cross-license agreement if the aggregate optimism is larger than a threshold $y(k)$. The fact that bargaining delay can be caused by excessive optimism due to the lack of common prior is not a novel result. In fact, my example is very similar to two period negotiation models proposed by legal scholars (see for example Landes (1971), Posner (1972) and Babcock and Loewenstein (1997)) to explain how "divergent expectations" can cause failure to settle.

What differentiates my simple example from previous literature is that in my setting it is possible to notice that the level of optimism required to delay a broad cross-license is increasing in k, that is:

$$
sgn\left\{\frac{dy(k)}{dk}\right\} = sgn\left\{V - 4L\right\} > 0.
$$

This result implies an equilibrium pattern similar to the one depicted in figure 1. In this figure it is possible to notice that, given an initial value of optimism y, there is not going to be agreement if $k \leq \underline{k}$ and there is going to be immediate agreement if k exceeds a threshold k^*.

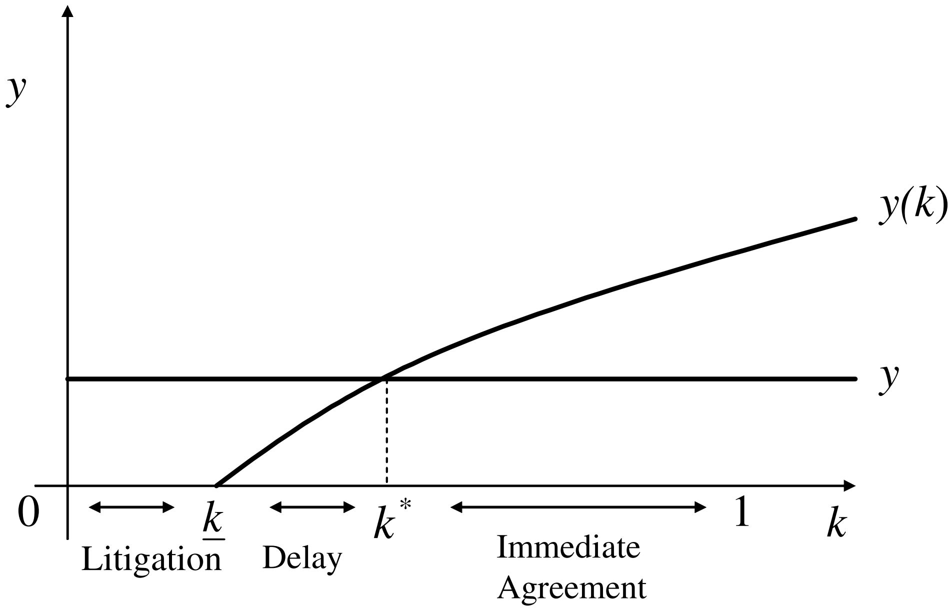

Figure 1: Asset Specificity and Equilibrium

More interestingly, inefficiencies arise for intermediate levels of sunk costs. In fact, if $\underline{k} \leq k \leq k^{*}$, despite both firms know that with an immediate cross-license agreement they can increase their joint surplus, they prefer to delay the agreement of one period. The reason for this delay is that, because of optimism, the share of surplus that firm 2 requires in order to accept the contract is considered excessive by firm 1. In this case, firm 1 prefers to wait one period, to let optimism disappear, and to obtain a larger expected share of future surplus. As k increases, the cost sustained by firm 2 in case of delay gets larger; this reduces its requested share of surplus and allows firm 1 to offer an immediately acceptable contract.

3 The General Bargaining Game

The above example illustrates how investment in specific technology not only plays a fundamental role in determining whether or not two firms will cross-license their intellectual property, but also influences the timing of the agreement.

However, this simple example, though suggestive, has some limitations. First of all, as Yildiz (2003) points out, the presence of delay relies critically on the assumption that there are only two periods. In particular, it is possible to show that if optimism is sufficiently persistent and the horizon of the game is long enough, then firms will agree immediately. The intuition for this result is quite simple: with persistent optimism and sufficiently long horizon, firms will anticipate that in the case of initial disagreement there is going to be a very long delay and they will prefer to agree immediately.

Second, excessive optimism alone seems inadequate to explain cross-licensing delay in the semiconductor industry. A more appealing justification for this delay would involve some learning by firms during patent litigation.

Third, in the former example I assumed that moving from a monopoly to a duopolistic market structure there was no revenue dissipation. Removing this assumption can help understanding how product market competition may affect cross-licensing.

In this section, to address these concerns, I generalize the example developing an infinite horizon model of bargaining with learning. The model combines a litigation framework similar to the one in Lanjouw and Lerner (2001) with the bargaining game with learning developed in Yildiz (2003, 2004). In particular, I extend Yildiz (2004) framework in two directions: first, in my model firms bargain over the surplus generated by a cross-license agreement and not over a pie of fixed size, second, in case of disagreement firms get a per-period outside option that correspond to their litigation payoff.

3.1 Framework

As in the previous example, I consider a setting with two semiconductor firms $N = \{1, 2\}$ but I generalize the model to study an infinite stream of innovations. Each innovation is going to be embedded in a product at a cost of F, it gives revenue for one period only and then is exogenously replaced by a new innovation. In each period nature recognizes one of the two firms as a patentee-producer facing an infringing action on the part of the other firm (the infringer). The profits for the patentee if it is the unique user of the innovation are $V - F$. If infringer and patentee both use the innovation each of them obtains a profit of $\alpha V/2 - F$ where the parameter $\alpha \leq 1$ captures the level of product market competition. In the absence of a cross-license agreement the patentee goes to trial. In this case both players will have to pay a legal cost L and I assume that with probability $1/2$ the patent is found to be infringed and with probability $1/2$ it is not.

Therefore the patentee expected payoff from the period litigation is

$$\overline{u} = \frac{1}{2}(V - F) + \frac{1}{2}(\frac{\alpha V}{2} - F) - L \tag{4}$$

whereas the expected payoff for the infringer is:

$$\underline{u}(k) = \frac{1}{2}(\frac{\alpha V}{2} - F) - \frac{1}{2}kF - L \tag{5}$$

where $k \in [0, 1]$ is a parameter indicating firm investment in specific assets.

Firms discount future with a discount factor $\delta < 1$. I assume that in each period firm 1 is chosen to be the patentee with probability ρ and firm 2 is chosen to be the patentee with probability $1-\rho$. Following Yildiz (2003), I assume that firms do not know ρ and they have two different priors about it. It is possible to interpret this difference in beliefs about nature recognition process as a difference in beliefs about each player's bargaining power. In fact, because in sequential offer bargaining models a player's bargaining power is eventually determined by the recognition process, the latter can be used to metaphorically describe the former. This relation between relative offer frequencies and bargaining power have been previously noted by Binmore *et al.* (1986) exploring the relationship between the Rubinstein noncooperative bargaining game and the weighted Nash bargaining solution. In addition, two results in Yildiz (2004) confirm that this intuition is adequate in my model: first a firm's equilibrium payoff is the present value of all rents it expects to extract when it offers in the future, second a firm i becomes better off in equilibrium whenever each player comes to believe that i has higher probability of recognition in the future.

I consider the following timing. At $t=1$ nature recognizes the first period patentee. The two firms observe this selection and update their beliefs. The chosen patentee offers to the infringer a share of present and future duopolistic profits. If the infringer accepts this offer the game ends and the firms enjoy the stream of future duopolistic profits according to the share proposed by the patentee. If it rejects they both receive the litigation payoffs for one period and nature selects who is going to make the offer in the following period. Firms observe who is chosen, update their beliefs and the game proceeds for an infinite horizon. The actual game tree is specified in the following figure 2.

To solve this infinite horizon bargaining game I need to assume some restrictions on players' beliefs. Following Yildiz (2003) I assume that they have beta distributions. Fixing any positive integers $\overline{m}_1$, $\overline{m}_2$ and n with $1 \leq \overline{m}_2 \leq \overline{m}_1 \leq n-2$, I assume that for any given dates t and s with $s \geq t$, at the beginning of date t if a firm i observes that firm 1 has made m offers (and firm 2 has made $t-m$ offers), then it assigns probability

$$\frac{\overline{m}_i + m}{t+n}$$

to the event that firm 1 will make an offer at date s.

This belief structure arises when each player believes that the probability of firm 1 making an offer at any date t is identically and independently distributed with some unknown parameter ρ that is distributed with a beta distribution with parameters $\overline{m}_i$ and n. As Yildiz (2004), I assume that everything about this beliefs structure is common knowledge.

Write $p_t^i(m)$ for the probability firm i assigns at (m,t) to the event that it will offer at any date $s \geq t$. Now, each firm i thinks at (m,t) that the probability that the other firm j will offer at date s is $1-p_t^i(m)$ while firm j thinks that it will offer with probability $p_t^j(m)$ which is higher than $1-p_t^i(m)$ as I will show shortly. This difference indicates that player i thinks that j is optimistic. Since each player thinks that the other player is optimistic, following Yildiz (2004), I will say that the players

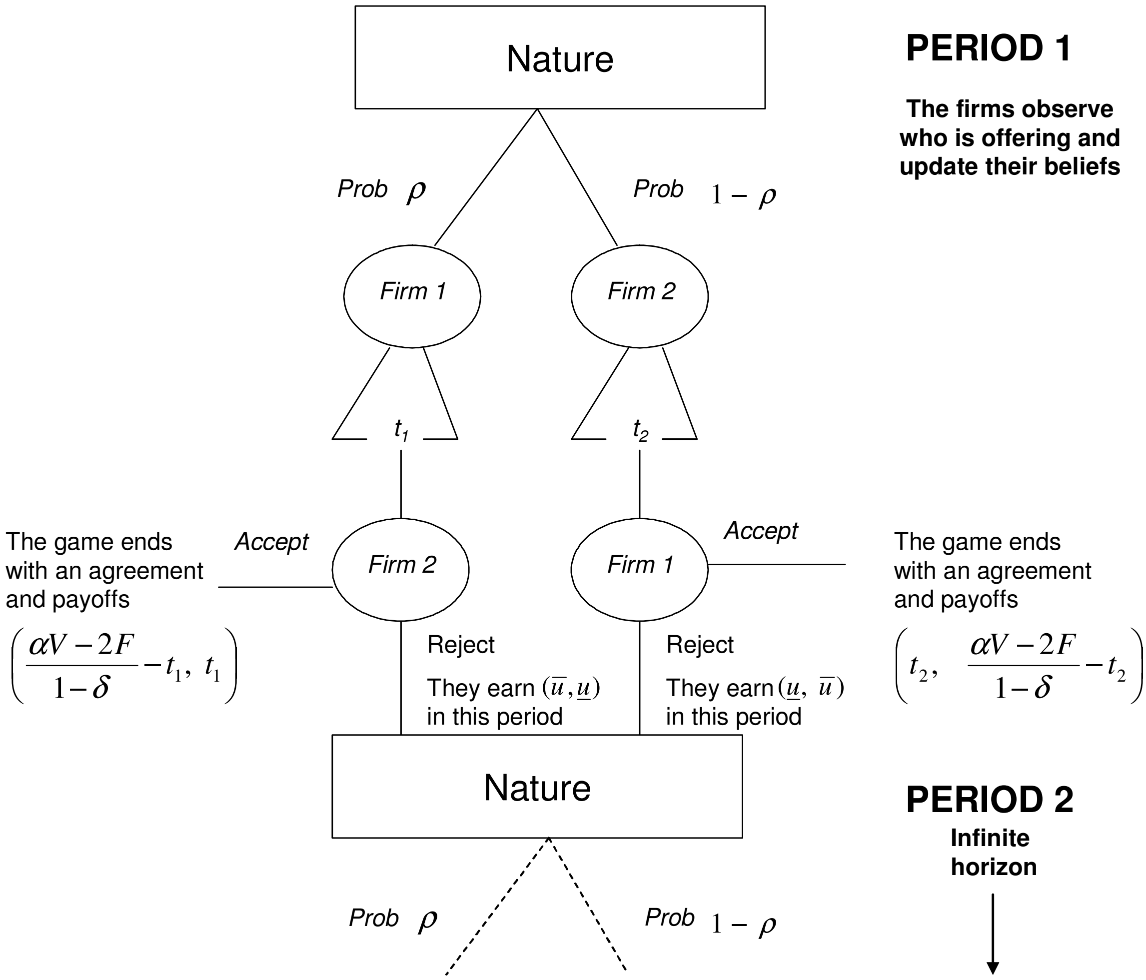

Figure 2: Game Tree

are optimistic at (m, t).

I define

$$y_t(m) = p_t^1(m) + p_t^2(m) - 1$$

the level of aggregate optimism at (m, t). Because of the beta distribution that has been assumed:

$$y_t(m) = \frac{\overline{m}_1 - \overline{m}_2}{t + n} = \frac{\Delta}{t + n} > 0.$$

The previous formula has three important implications. First, since $y_t(m) > 0$, the players are indeed optimistic at each (m, t). Second, y_t is deterministic: it does not depend on m and therefore it is possible to suppress m from the notation. This is due to the assumption that n is the same in both distributions and it greatly simplifies the analysis. Third, as t gets larger, firms' beliefs converge and firms learn the actual ρ.

Finally, I assume the following parameter restriction:

$$\frac{\alpha V}{2} > F > 4L. \tag{6}$$

The first inequality is necessary to have positive duopolistic profits and both firms producing in the case of invalid patent. The second inequality implies an upper bound to litigation costs. In particular, combining the two inequalities, total legal costs ($2L$) cannot exceed one-quarter of the total duopolistic revenue and this is in line with standard assumptions in the patent litigation literature (see Lanjouw and Lerner (1998)).

3.2 Testable Predictions

To understand the effects of firm sunk costs, consider the per-period surplus. If a cross-license agreement is reached both firms produce and sell the product and the total per-period surplus is going to be $\alpha V - 2F$. Conversely, if litigation occurs then total per-period surplus depends on the court decision and in expectation is given by:

$$\overline{u} + \underline{u}(k) = \frac{1}{2}(V - F - kF) + \frac{1}{2}(\alpha V - 2F) - 2L.$$

It is easy to see that $\alpha V - 2F > \overline{u} + \underline{u}(k)$ only if $k > 1 - 4L/F + V(1-\alpha)/F \equiv \underline{k}$ i.e. a cross-license agreement is efficient only for large values of asset specificity. This threshold implies that in a model without optimism there will be a discontinuity in the outcome of a cross-license bargaining game. In fact, whereas in the inefficient region ($k \leq \underline{k}$) firms will never agree on a cross-license, for $k > \underline{k}$ there will be immediate agreement.

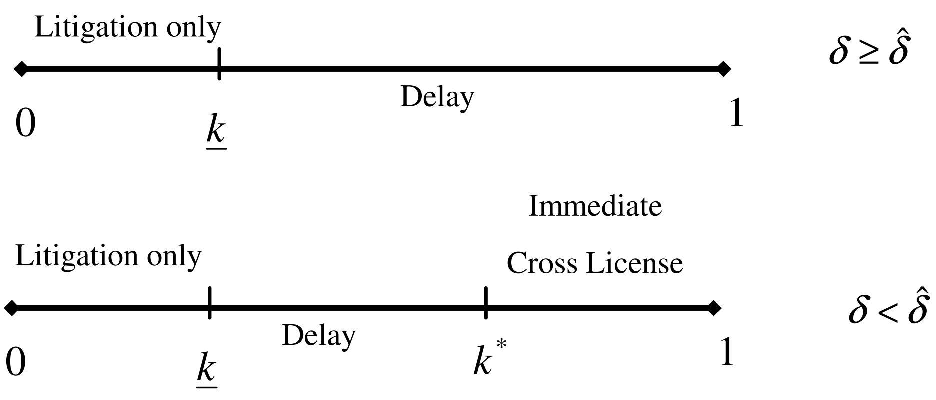

Figure 3: Equilibrium Outcomes

Introducing optimism may remove this discontinuity in the outcome of the bargaining game. In particular, in the case in which a cross-license is efficient, an agreement may be reached with delay. The following proposition characterizes the unique Markov perfect equilibrium of this infinite horizon game in which player strategies only depend on how many times firm 1 has been recognized.

Proposition 1 *For $k \leq \underline{k}$ litigation is efficient and a cross-license agreement never occurs. For $k > \underline{k}$ players sign a cross license-agreement. For any Δ, n there exist $\widehat{\delta}$ and k^* such that:*

1. *for $\delta \geq \widehat{\delta}$ there is always agreement with delay*
2. *for $\delta < \widehat{\delta}$ there exists a k^* such that if $k \geq k^*$ there is immediate agreement and there is agreement with delay if $k^* > k > \underline{k}$.*

Proof. See Appendix. ■

The content of the proposition is illustrated in figure 3. For low values of k the size of the outside option is greater than the surplus that can be shared cross-licensing and therefore there is never agreement. When k exceeds $\underline{k}$, agreement becomes efficient and can be reached with or without delay. In particular, there is immediate agreement if δ is low and k is large.

The equilibrium timing for the agreement is determined by a trade-off between the benefit and cost from waiting one period. As in Yildiz (2004), my bargaining game is based on a tension between learning and the discount factor. On one side, optimism induces both parties to delay the agreement because the overestimated bargaining power renders expensive for the patentee to offer to the infringer its expected continuation value. Because of learning, waiting one period will reduce infringer's requested share and will allow the patentee to obtain a better deal. On the other side, the discount factor reduces the value of future payoffs and induces parties to agree immediately.

Differently from Yildiz (2004), my model considers additional variables that can influence the agreement timing. In particular, asset specificity plays a fundamental role in my bargaining game. More specifically, an increase in k has two effects. First, it renders more costly for the infringer to reject an offer. This increases the rent that the patentee can extract with an immediate agreement and induces the parties to agree without delay. Second, it increases rents that future patentees will be able to extract. This effect increases the marginal benefit of waiting (because optimism is attached to larger rents) and induces parties to delay the agreement. For δ low enough, the first effect dominates the second and an increase in sunk costs renders more costly for the parties to delay the agreement.

3.3 Discussion of the Main Assumptions

The model builds on a number of assumptions which are worthy of additional discussion.

First, in modeling infringer's payoff I assumed that in the case of patent infringement it sustains a cost that increases with its investment in specific technology. The fact that the cost associated with stopping production or varying production processes increases with firm' sunk costs has been already emphasized in the literature. In particular, Hall and Ziedonis (2001) and Ziedonis (2004) discuss field interviews in which it clearly emerges how the losses due to halting or altering production processes are more detrimental for firms investing intensively in product specific manufacture facilities. Also Shapiro (2001) points out that the hold-up problem is more serious for manufacturers with large sunk costs. A micro-foundation of this cost can be easily provided assuming that each innovation can be embedded in a product investing in equipment that costs F and that a fraction $k \leq 1$ of this cost is sunk. In this framework, if the infringer has to halt its production, it can resell only the non-sunk part of its equipment. In this setting, a larger k can be mapped into lower revenue from reselling the equipment after halting production. As in my model for k large enough cross-license is the efficient alternative.

Second, I assume that in negotiating a cross-license agreement the patentee makes a take it or leave it offer that does not depend upon future recognition and quantity produced. In particular, I do not consider more sophisticated licensing mechanisms as those presented in Kamien and Tauman (1986, 2002) and in Katz and Shapiro (1985). The main reason for this assumption is that in the data I did not find any empirical evidence of royalties or price fixing. Moreover, antitrust guidelines for the licensing of intellectual property specify that "when cross-licensing arrangements are mechanisms to accomplish naked fixed pricing or market division, they are subject to challenge under the per-se rule".[5]

[5] See Department of Justice (1995).

Third, I assumed that in case of disagreement over a cross-license firms have to resolve their period dispute by litigation. This assumption greatly simplify my analysis but it can be removed. If I replace litigation with private settlement, results keep being valid as long as firms have to sustain a cost $l < L$ in order to reach the settlement. In addition, I can assume that private settlement is costless introducing some informational asymmetry over the patent infringement (as in Bebchuck (1984)) that might lead with some positive probability to parties' failure to settle. Also in this case the main results will still be valid.

As Yildiz (2004) points out, it is important to notice that there is no inconsistency in combining rationality assumptions with heterogeneous prior beliefs. In fact Savage (1954) discusses how these assumptions are not related and Morris (1995) shows that rationality arguments in favour of the common prior assumption are rather weak. My paper contributes to a strand of growing literature of applied theory that shows how it is possible to obtain precious insights relaxing the common prior assumption.[6]

Finally I discuss the choice of Yildiz (2004) bargaining framework. There are various theoretical papers analyzing how delay in bargaining can be obtained from different mechanisms. Kennan and Wilson (1993) review the literature in which delays arise because of the presence of private information. In fact, private information can induce delay due to signaling, screening or attrition purposes. Additionally, delay can be generated in games with simultaneous offers as Perry and Reny (1993), in models with more than two players as Cai (2000) or introducing transaction costs as in Anderlini and Felli (2001). Among all these mechanism I adopted Yildiz (2004) framework because it allows to generate delay due to parties' willingness to learn their pattern of future infringements. Managerial literature has pointed out how relevant this feature is in semiconductor cross-license negotiation (see for instance the Texas Instrument case study in Grindley and Teece (1997)). In fact, this literature describes how delay in these negotiations are often generated because of extensive reverse engineering that parties carry out in order to evaluate their dependence upon counterpart intellectual property.

4 Data

Following Hall and Ziedonis (2001), I identified from Compustat the universe of publicly traded U.S. firms whose principal line of business is semiconductor and related devices (SIC 3674) and that have data from 1998 to 2003. I then matched these firms with data of the NBER Patent Data file obtaining information on patent activity of these firms from 1963 to 2002. I restricted the dataset to firms having some patenting activity after 1988 and I obtained a sample of 95 companies.

For all these 95 firms, I collected information both on their cross-license agree-

[6] Among the various contributions see Watanabe (2005) and Roth (1996) for industrial organization settings and Morris (1994) or Harrison and Kreps (1978) for financial market applications.

ments and on their patent litigation from the U.S. Security and Exchange Commission fillings that these companies filed for the period 1994-2004. Examining these documents, I identified 24 broad **cross-license** contracts. More precisely, I defined an agreement as a "broad cross-license" if either firms cross-licensed their entire patent portfolios (20/24 agreements) or they cross-licensed patents in some extensive technology group (e.g. memory devices). The detail of information disclosed varies across firms: some filings indicate only the existence of the contract others are more accurate disclosing terms and financial conditions.[7]

Only 25 of the 95 firms in the sample are involved in cross-license agreements. Nevertheless these firms carry out 84.29% of the patent activity in the sector during the period 1998-2002. In addition, I found that the links created by cross-license agreements between firms are not completely random. Firms appear to be organized into two well defined star networks one with centre on Texas Instruments Inc. and another one with a core formed by four companies: Intel Corporation, Broadcom Corporation, National Semiconductor Corporation and Agere Systems Guardian Corporation.

In addition, from the SEC filings, I obtained data on **patent litigation** among firms in the sample for the period 1994-2004 . I define patent litigation as an uninterrupted period of patent dispute between two companies, independently of the identity of the infringer and the number of sues and counter-sues. I registered 38 cases of patent litigation among firm pairs in the sample.

For each company I computed the patent **portfolio** as the sum of patents obtained by the company from 1988 to 2002.[8] Moreover, for all firm pairings I measured the asymmetry between the two portfolios computing the **ratio** between the larger and the smaller. In addition, for each firm I measure its **patent intensity** as the ratio of its portfolio and the number of its employees.

To measure **product market distance** I used two distinct measures. The first is based on the World Semiconductor Trade Statistics (WSTS) "Blue Book" report. The WSTS is a non profit corporation providing data collection on semiconductor trade. From this publication I identified 23 broad product categories. Combining this information with data obtained from firm catalogs I constructed for each firm a vector $s_i = (0, 1, 0, ..., 0)$ where the jth entry is 1 if firm i is selling some product in category j. With these vectors I computed the **SIC** distance as in Bloom, Schankerman and

[7] As an example we report an extract from the Form 10-K deposited by Micrel Inc. describing its agreement with National Semiconductor Corporation: "*On May 23, 2002, the Company entered into a Patent Cross License and Settlement Agreement with National Semiconductor which settled all outstanding patent disputes between the companies and **cross licensed the entire patent portfolio of each company**. Some of the National patents within certain field of use areas are licensed for the life of the patents, all other patents of both companies are licensed through May 22, 2009. Under the terms of the agreement Micrel agreed to pay National $9.0 million.*"

[8] To construct the portfolios we considered the patents directly obtained by the company and those obtained by firms merged or aquired by the company in the period 1988-2002.

Van Reenen (2005) (henceforth BSV):

$$SIC_{ij} = \frac{s_i' s_j}{(s_i' s_i)^{\frac{1}{2}} (s_j' s_j)^{\frac{1}{2}}}.$$

Secondly, I exploited the very same data used in the BSV paper. I obtained sales of the firms in seven 4-digit SIC codes lines of business and I computed the average share of sales per line of business within each firm over the period 1993-2000. I let $S_i = (S_{i1}, ...S_{i7})$ denote the distribution of sales of firm i across SIC codes. Following BSV, I computed the **BSVSIC** as the uncentered correlation across all firms pairings:

$$BSVSIC_{ij} = \frac{S_i' S_j}{(S_i' S_i)^{\frac{1}{2}} (S_j' S_j)^{\frac{1}{2}}}.$$

The two product market distances presented are both imperfect measures of similarity among firms manufactured goods. In particular SIC is quite detailed but it does not consider the relative importance of a product class on firms revenue. Conversely BSVSIC gives different weights to different product categories according to their impact on company sales but it is based only on seven broad SIC codes.

The **technological correlation** is measured using the 426 technology classes (N-classes) provided by the USPTO. Following Jaffe (1986, 1988) and BSV (2005) I used the average share of patents per firm in each technology class over the period 1988-2002 to construct the vector $t_i = (t_{i1}, t_{i2}, ..., t_{i426})$ describing the distribution of patents of firm i across technological classes. The technological closeness measure TECH is calculated as the uncentered correlation between all firms pairings:

$$TECH_{ij} = \frac{t_i' t_j}{(t_i' t_i)^{\frac{1}{2}} (t_j' t_j)^{\frac{1}{2}}}.$$

In addition, I constructed a measure of **linkages** between firms using the NBER Citation Data file. For each firm pair ij I computed the fraction of firm i citations that referred to firm j patents and the fraction of firm j citations referring to firm i patents. I averaged these two values weighting them with firms total number of citations. More formally my index is:

$$LINK_{ij} = \frac{\#\text{ citations from } i \text{ to } j + \#\text{ citations from } j \text{ to } i}{\#\text{ citations of } i + \#\text{ citations of } j}.$$

It is important to note how the LINK measure differs from the TECH measure. TECH quantifies the proximity between two firm research activities in the 426-dimensional space generated by the USPTO N-classes. A large value for TECH implies that the portfolios of the two firms are very similar and can be interpreted as a proxy of *substitutability* between patents in the two portfolios. Conversely LINK measures direct linkages between the two firms. A value of LINK close to one implies that most of firm i research activities rely on firm j patents and therefore can be interpreted as an evidence of *complementarity* between the two portfolios.

To capture firm asset specificity, I adopt two alternative measures. First, as Hall and Ziedonis (2001), I use capital intensity defined as the ratio of plant and equipment to employees of each firm in year 2002.

In particular, for each firm pairing I compute the average of the two firms' capital intensities. In addition, to consider the asymmetries between the two capital intensities I computed the ratio (max/min) between the indexes. Both average capital intensity and the capital intensity ratio have been calculated for the gross figure of property plant and equipment and for the net figure (i.e. subtracting accumulated depreciation).

Hall and Ziedonis (2001) and Ziedonis (2003, 2004) provide various justifications for the use of this capital-labor ratio as a proxy for the cost involved with halting production. In particular, from their field interviews and their analysis of data from the Integrated Circuit Engineering Corporation, Hall and Ziedonis (2001) observed that in the semiconductor industry this capital intensity measure appears to be highly correlated with sunk costs. Moreover, Hall and Ziedonis (2001) argue that fabrication facility expected life span has significantly decreased during the nineties, making these investments more and more product specific. In addition they illustrate that the cost of equipment needed for a new semiconductor fabrication plant is very large (in 1998 it was estimated as more than \$1.5 billion) and that it has increased (and is expected to keep increasing) over time, rendering equipment and machinery the largest component in the plant and equipment figure.

As additional measure, I developed an alternative sunkness index based on firms' technological information. In particular, exploiting information obtained from firms' product catalogues and SEC filings, I classified firms according to four product categories they produce: microprocessor chips (group 3), memory chips (group 2), programmable logic (group 1) and others (group 0). Literature on the semiconductor industry (e.g. Turley (2005)) points out how the sunkness of the equipment tends to decrease as we move from products in group 0 to products in group 3[9]. As for the capital intensity measure, for each firm pair I computed the average between firms' sunkness indexes.

The unit of observation in the empirical analysis is going to be a firm pair. In particular, using the 95 firms in the sample, I constructed a data set of 4465 pairings ($95 \times 94/2$).

In table 1, I present some summary statistics for the various variables across pairings in the dataset. Total Portfolio indicates the sum of the two portfolios whereas

[9]From an email exchange with Texas Instruments engineers I obtained additional support to this classification.

Portfolio Ratio indicates the ratio between the greater and the smaller portfolio in the pair. Similarly, Average Capital Intensity indicates the average between the two firm capital intensity indexes and Capital Intensity Ratio indicates the ratio of the maximum over the minimum. Table 1 also provides summary statistics for the four measures of technological similarity and product market closeness. The values obtained are similar to those obtained by Ornaghi (2005) for a sample of pharmaceutical firms. It is important to note the difference in the distribution of the two measures of product market similarity. The SIC measure, because of its greater detail, appears highly skewed to the left (its median is zero) whereas BSVSIC emerges as highly skewed to the right (its median is 0.707).

The correlation among the four distance measures is presented in table 2. The correlation between product market and technological distances appears quite low. In particular, it is lower than the one obtained in BSV but in line with the values obtained by Ornaghi (2005). As discussed above, both SIC and BSVSIC are unsatisfactory measures of firm product differentiation. Their imperfection is straightforwardly observed from the very low correlation between them.

Across these pairings, I identified those having disclosed cross-license agreements or patent litigation. Examining the information I collected from firm SEC filings, it is possible to observe that for only one percent of the firm parings there is some form of interaction. Interestingly, all three patterns predicted by the theoretical model emerge from the data:

1. for 22 pairings, firms litigated and terminated the litigation (either with a trial judgment or with a private settlement) without signing a cross-license agreement;

2. for 16 pairings, firms litigated and terminated the litigation with a settlement involving a cross-license agreement;

3. for 8 pairings, firms signed a cross-license agreement without previous litigation.

The fact that for most of the pairings I register neither litigation nor cross-license is a relevant aspect of the data and will play an important role in the econometric analysis.

I define now the dummy variable CONTACT. I let this variable take value equal to one if there is evidence of either litigation or cross-license between firms in a pairing. As I discussed above, CONTACT is zero for 4419 pairings and one for 46 pairings only. In table 3, exploiting this dummy, I compare variable means of firm pairings for which I register interaction and with those of pairings for which I do not observe it.

At a first look, firm pairings involved in litigation or cross-licensing appear to have a greater total portfolio, larger size and greater average patent intensity. In addition, they seem closer both in the technology space and in the product market dimension.

Moreover firm technological linkages look much stronger among firms with a positive value for CONTACT.

In table 4, I look more in detail to pairings disclosing some form of interaction. More precisely, in this table I classify firm pairings according to the way they resolved their patent disputes. Specifically, in the first column of table 4 I report averages for firm pairings involved in litigation only, in the second column for those litigating and then cross-licensing and in the third column for those cross-licensing without litigation.

Performing a one-way ANOVA test, I notice that the only variables that appear statistically different across the three groups are those related to firm capital intensities. Therefore, from the analysis of these summary statistics I conclude that whereas there are a number of variables correlated with the likelihood of observing a dispute between two firms, the actual choice of the dispute resolution technique appears only correlated with firms' capital intensity and not with other variables.

In particular, consistently with the model, the first look at the figures suggests that firms pairings with low average capital intensity tend to litigate without signing a cross-license agreement, that those with intermediate average capital intensity tend to litigate before cross-licensing and, finally, that those with high average capital intensity are inclined to cross-license immediately. In the next section I am going to evaluate whether the impressions from these summary statistics carry over to a formal econometric analysis.

5 Econometrics

In this section I describe the econometric techniques I adopt to analyze firm choices between cross-licensing and litigating. To this end I introduce a new ordered variable that I label OUTCOME. This variable is taking value of 1 if there is litigation without cross-licensing, value of 2 if litigation has concluded with a cross-license agreement and finally it is equal to 3 if there is agreement without any previous litigation. More precisely, I consider OUTCOME as an ordered variable in the sense that its three values correspond to decreasing willingness to delay a cross-license agreement. In particular, I assume it varies according to a latent variable y_{2ij}^* (to be interpreted as impatience to cross-license) in the following way:

$$OUTCOME_{ij} = \begin{cases} 1 & \text{if } \ y_{2ij}^* < c_1 \\ 2 & \text{if } \ c_1 < y_{2ij}^* < c_2 \\ 3 & \text{if } \ y_{2ij}^* > c_2 \end{cases}$$

and

$$y_{2ij}^* = x_{2ij}'\beta_2 + u_{2ij},$$

where x_{2ij} and β_2 denote the vectors of explanatory variables and parameters and u_{2ij} is the error term. I set OUTCOME$_{ij}$ equal to zero if no dispute is observed between i and j.

There is a problem in estimating this ordered probit model and it is the fact that the probability of observing a dispute about intellectual property can depend upon variables that are different from those affecting the dispute resolution technique. Figure 5 describes this nested aspect that I have to consider in estimating the determinants of cross-licensing.

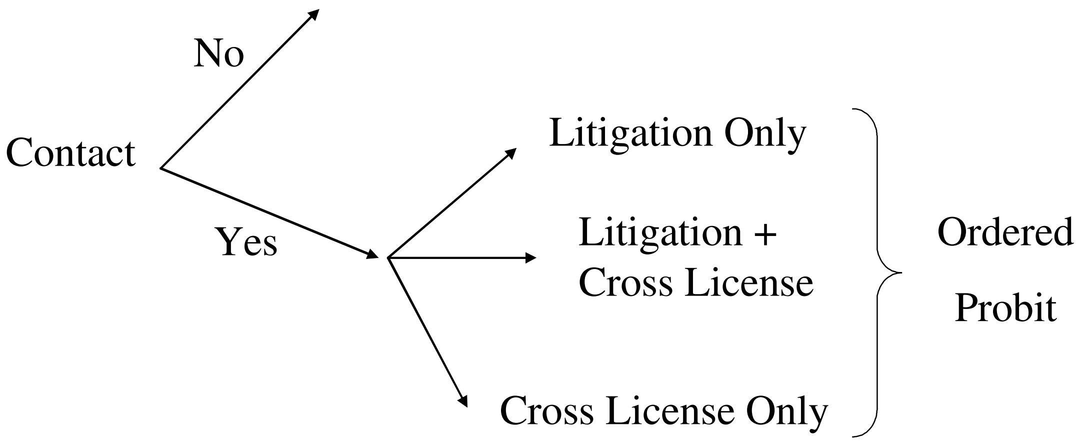

FIGURE 5: Nested Aspect of Disputes

For this reason, following Amemiya (1984), I use a Type II Tobit model where the probability of observing a dispute is captured by the dichotomous variable CONTACT that varies according to the value of a latent response variable y_{1ij}^* in such a way that:

$$CONTACT_{ij} = \begin{cases} 1 & \text{if } \ y_{1ij}^* > 0 \\ 0 & \text{if } \ y_{1ij}^* < 0 \end{cases}$$

where

$$y_{1ij}^* = x'_{1ij}\beta_1 + u_{1ij} \qquad ij = 1, ..., n(n-1)/2 \tag{7}$$

and x_{1ij} and β_1 denote the vectors of explanatory variables and parameters and u_{1ij} is the error term. I assume that $\{u_{1ij}, u_{2ij}\}$ are i.i.d. drawings from a bivariate standard normal distribution with correlation coefficient ρ.

In this setting Amemiya (1984) shows that:

$$\begin{aligned} E[y_{2ij}^* | x_{2ij}] &= x'_{2ij}\beta_2 + E[u_{2ij} | CONTACT_{ij} > 0\ ] \\ &= x'_{2ij}\beta_2 + E[u_{2ij} |\ u_{1ij} > -x'_{1ij}\beta_1] \\ &= x'_{2ij}\beta_2 + \rho \frac{\phi(x'_{1ij}\beta_1)}{\Phi(x'_{1ij}\beta_1)} \end{aligned} \tag{8}$$

where $\phi(.)$ is the standard normal density and $\Phi(.)$ its cumulative distribution function. It is therefore easy to see why the estimation of (8) may be biased whenever ρ is not zero.

To correct for this bias, and following Van De Ven and Van Praag (1981), I construct a likelihood function based on equations (7) and (8):

$$L = \prod_{CONTACT=0} P(\, y_1^* \leq 0) \prod_{OUTCOME=1} P(\, y_2^* < c_1 \ \wedge \ y_1^* > 0)$$
$$\prod_{OUTCOME=2} P(\, c_1 \ < \ y_2^* < c_2 \wedge \ y_1^* > 0) \prod_{OUTCOME=3} P(\, c_2 < y_2^* \ \wedge y_1^* > 0).$$

Given the assumptions on the distribution of $\{u_{1ij}, u_{2ij}\}$ it is possible to express this likelihood function in terms of cumulative normal distributions, I describe how to derive this formula in the appendix. It is interesting to note how the first part of this likelihood resembles the likelihood for a conventional probit, whereas the second part resembles the ordered probit on those sample points that have a positive OUTCOME value.

5.1 Discussion

I begin the empirical investigation analyzing the determinants of firm interactions. To this end, I estimated the probability of CONTACT with various probit regressions. As described in section 4, I assign a positive value to this dummy variable if a firm paring discloses either litigation or cross-licensing. Results for these regressions are reported in table 5. The main outcome of these estimations (and of others not reported) is captured by the first column of the table: the probability of observing some form of CONTACT between two firms depends on their technological closeness, on the linkages between them and on the size of firm portfolios. In fact total portfolio, TECH and LINK are the only variables that show up significant at the 0.01 level.

Significance of these variables persists when I introduce additional controls and nonlinear effects. For example, in column (2) I show that there is no evidence of quadratic effects for total portfolio. Similarly, in non reported regressions, I observed that analogous non-linear effects do not show up for TECH and LINK. In addition, I do not find significance for interactions between LINK, TECH and total portfolio (marginal effects computation follows Ali and Norton (2003)).

In columns (3) and (4) I show that the measures of product market similarity, and the index of sunkeness do not seem related to the probability of interaction. Finally, in column (5), I show that capital intensity, employment and patent intensity do not affect the probability of interaction.

In all estimations, the effect of the TECH variable appears to be stronger than the one of the LINK measure. In fact the marginal effect for TECH is 0.018 and its correspondent elasticity at the mean is 0.82 whereas for LINK the marginal effect is 0.004 and the elasticity is 0.003. More precisely, whereas a one standard deviation increase of TECH raises the probability of interaction of 0.004, a one standard deviation increase in LINK raises this probability of 0.0001 only.

The marginal effect of total portfolio is positive and its elasticity at the mean is 0.22. As it is possible to observe from table 6, if the values of TECH an LINK are kept constant at their means, the marginal effect of total portfolio does not seem to vary across its distribution. In fact both for the total portfolio median paring (133 patents) and for the 90th percentile pairing (2173 patents) an increase of 100 patents raises the probability of interaction of 0.0001.

For simplicity, in the theoretical model I assumed that the infringement disputes were arising exogenously in each period. The constant total portfolio marginal effect offers some indication on how it can be possible to extend the model introducing a probability of infringement that depends linearly on firm total portfolio. Consider the following simple example: there are 2 firms A and B with n_A and n_B patents respectively. Let us assume that each patent of firm A is infringed by firm B with probability α, that each patent of firm B is infringed by firm A with probability α and these probabilities are i.i.d. across patents and firms. Then firm A will not infringe any patent of firm B with probability $(1-\alpha)^{n_B}$ and similarly firm B will not infringe with probability $(1-\alpha)^{n_A}$. Therefore at least one infringement will arise with probability $1-(1-\alpha)^{n_A} * (1-\alpha)^{n_B} = 1-(1-\alpha)^{n_A+n_B} \simeq (n_A+n_B)\,\alpha$ for α low enough that is linear in n_A+n_B. Therefore, combining this simple example with the empirical finding, I conclude that it is plausible to assume each patent to be infringed with a constant and independently drawn small probability.[10]

Exploiting these probit regressions, I performed various ordered probit estimations correcting for the selection bias.

Results for some of these regressions are reported in table 7. For these regressions, the identification strategy is to assume that TECH does influence the probability of observing a dispute but it does not influence the choice of dispute resolution technique.

In unreported regressions, I tested various alternative identification strategies. In most of the regression performed, correlation between the two error terms is not

[10]At a first sight, this constant marginal effect appears in contrast with the estimates in Lanjouw and Schankerman (2004). In fact, in a sample of 17,443 patents in eight broad technology groups, they show that patent litigation probability is negatively related to the size of firm patent portfolio. To understand the divergence between the two estimates it is important to understand how their empirical question differs from the one in this paper. Lanjouw and Schankerman (2004) compute the litigation probability at a patent level, i.e. the likelihood that a randomly drawn patent in a portfolio is litigated. Differently, in the probit regressions reported in table 5, I consider the probability of interaction for a firm pairing. The setting is therefore different and, in particular, two features of the data may help explaining the difference in the results. First, in considering interactions among firms, I do not restrict the analysis to litigation but I also include cross-licensing. Second, a reduction of the litigation probability at patent level does not necessarily reduce the litigation probability at firm level, in fact this probability will increase as long as the portfolio elasticity is less than 1 in absolute value. In Lanjouw and Schankerman (2004) this elasticity is estimated (at means) to be 0.13, a value that is consistent with the positive marginal effect reported in table 6.

statistically significant and does not affect the main qualitative results. In particular, the absence of selection bias carries over even when I include in both stages of the regression the same vector of variables (see companion appendix for details).

Results in table 7 give empirical support to the testable predictions of the model. In fact, the analysis shows that once we correct for the probability of observing some form of interaction between two firms, their choice of dispute resolution technique appears correlated only with variables linked to their asset specificity: average capital intensity (in columns (1)-(3)) or average sunkness index in (column (4)).

In addition, the positive coefficients on these variables imply that, consistently with the model, firm pairings with low average capital intensity tend to solve their disputes litigating and not cross-licensing, firm pairings with intermediate values of capital intensity tend to delay cross-license agreements and pairings with large average capital intensity tend to cross-license avoiding litigation.

In columns (1) and (2) of table 7, I analyze the effects of product market relatedness. According to the theoretical model, it is reasonable to expect a negative coefficient on the product market distance measures. The data only partially support this result: the coefficients on both distances are never significant and always of the wrong sign. Nevertheless, generating a dummy variable that takes value one if both SIC and BSVSIC are above the 98th percentile, it is possible to notice that pairings very close in the product market space tend not to enter in a broad cross-license agreement. In fact, the coefficient of this dummy is negative and significant at the 5% level. (A more detailed analysis of the effects of both product market similarity and firm asymmetry is provided in the companion appendix).

6 Policy Implications

In this section I discuss some policy implications that can be obtained from the bargaining game.

The theoretical model unveils two types of patent litigation: efficient "perpetual" litigation and inefficient "persuasive" litigation. Firms with low asset specificity engage in "perpetual" litigation in the sense that they never reach a cross-license agreement. This kind of litigation is efficient because the payoff that they obtain by legally enforcing their intellectual property exceeds the payoff they would get from a cross-license. On the other hand, firms with intermediate values of sunk costs engage in "persuasive" litigation: they litigate in order to obtain a better deal in a cross-license agreement. This second type of litigation is inefficient because the joint payoff that parties would get by immediately signing a cross-license agreement does exceed the one they obtain litigating.

The model shows that not distinguishing between these two categories may have a serious impact on policy evaluation. More precisely, considering the amount of arising disputes as exogenous, a policy leading to an increase in the amount of litigation has to be evaluated differently depending on the type of litigation that it induces. In fact, whereas a policy leading to an increase of "perpetual" litigation increases firms joint payoffs, a policy inducing an increase of "persuasive" litigation reduces firms surplus.

In the following, I consider a policy experiment that can impact on cross-license decisions: a reduction in legal cost. More specifically, I model a reduction in legal cost with a decrease in the parameter L.

The analysis of this policy exercise is valuable to evaluate new proposals of patent litigation reform. In fact, various leading technology companies (including Intel, Cisco System and Hewlett Packard) have recently formed a coalition to lobby for patent litigation reform. While at present no formal list of members and policy goals has been released, a press report of the president of this coalition (Douglas Comer, Intel's director of legal affairs and technology policy) states:

> "*We are interested in improving the way remedies are applied, the way damages are assessed in the courts, and the function in the courts.*"

Analyzing various press releases and Senate testimonies[11] it appears that among the various suggestions, there are three reforms that companies seem to find necessary to restore fairness in the litigation system. First, to reduce the threat from **patent trolls**: companies that exist primarily to extract money from patent litigation and are exploiting the system to force lucrative settlements. Second, to eliminate **forum shopping**: plaintiffs should not be permitted to funneling cases into courts more predisposed to granting injunctions and defendants should not be able to target courts with the opposite bias. Third, to allow for **post-grant administrative reviews**. More precisely, the suggestion is to determine patent validity not through costly civil litigation but through administrative experts or through members of a technical agency.

If this lobby activity will reveal successful, and in particular if post-grant proceedings will be allowed, it seems reasonable to expect that the increase in court efficiency will lead to a reduction in firm litigation costs.

In my setting, a reduction in legal cost increases the total amount of litigation, but its effect on welfare is ambiguous as next proposition describes.

Proposition 2 *A decrease in L leads to an increase in $\underline{k}$ and in k^*.*

Proof. See Appendix. ■

What this result shows is that a reduction in L, increasing the level of k^*, increases the total amount of litigation. The shift in $\underline{k}$ is quite intuitive: there is an increase in the surplus from litigation that reduces the region where cross-license is efficient. Moreover, a reduction in legal cost reduces the cost of delay both for the infringer and the patentee, shifting k^* to the right. Figure 4 illustrates this finding.

[11] See in particular the testimony of Mark Chandler, Senior Vice President and General Counsel of Cisco Systems, "Perspectives on Patents: Post-Grant Review Procedures and Other Litigation Reforms" before the Senate Subcommittee on Intellectual Property on the Judiciary May 23, 2006.

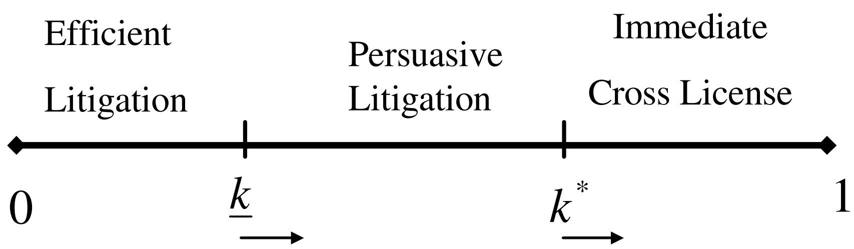

Figure 4: A Simple Policy Experiment

To evaluate the welfare impact of such an increase in total litigation, it is necessary to compare two opposite effects. On one side there is a welfare gain because of an increase in "perpetual" litigation due to a larger $\underline{k}$. This implies that some firms that before were sharing the duopoly surplus now are attaining a greater joint payoff enforcing their intellectual property rights. On the other side there is a welfare loss due to a shift in k^*. In fact, firms that before were immediately reaching a cross-license agreement are now engaging in inefficient "persuasive" litigation.

While the relative strength of the two effects will depend on model's parameters, an important role in the computation of the welfare impact will be played by the distribution of firms' investments in specific technology. In particular, the proposition implies that a reduction in legal costs is more likely to lead to inefficient litigation whenever the number of firms signing immediate cross-license agreements is large compared to those delaying the agreement.

The shift in $\underline{k}$ has a positive welfare impact: it implies that firms that previously were cross-licensing are now enforcing their intellectual property and therefore attaining a higher payoff. Conversely the shift in k^* has a negative impact on welfare: it means that firms that previously were cross-licensing immediately are now engaging in inefficient "persuasive" litigation and therefore attain a lower joint payoff. Clearly, the total welfare impact of the policy comes from the combination of these two effects. A precise computation of this welfare impact requires information on firm litigation costs and is beyond the scope of this paper; nevertheless, the dataset allows to evaluate the possible effects of the policy on the number of agreements in the semiconductor industry.

In particular, analyzing the distribution of firms' capital intensities, it is possible to obtain some indication of the number of firms likely to be affected by these marginal shifts.

Figure 5 plots the distributions of average capital intensities of all firm pairings for which I register some form of interaction. The two red lines represent the estimated thresholds that delimit the regions of litigation, delayed cross-license and immediate cross-license (backed-up from the ordered probit in column(1) of table 7).

From this figure it is evident that the number of firms around the first cutoff is

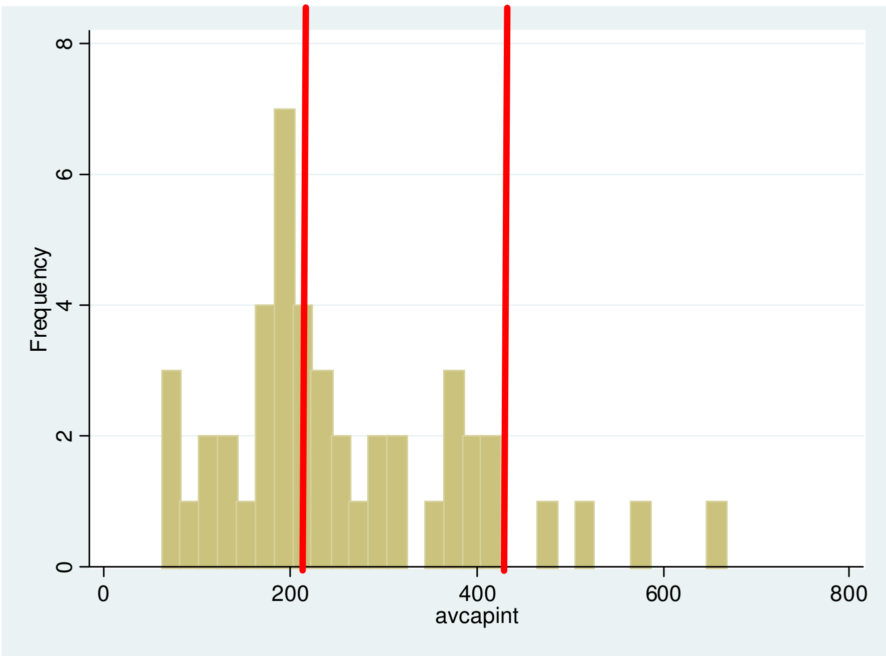

Figure 5: Capital Intensity Distribution and Litigation

much larger than the number of firms around the second. This implies that for many pairings the relevant trade-off lies in the choice between cross-licensing or not cross-licensing rather than in the choice between delaying the agreement or cross-license immediately.

To have a sense of the magnitude of the skewness in the distribution of capital intensity, I simulate a reduction in litigation costs leading to a right shift in both thresholds of one standard deviation of the average capital intensity distribution. As a consequence of this shift, I observe eight firm pairings switching from persuasive to efficient litigation and only one pairing switching from immediate cross-license to inefficient litigation.

From this simple exercise, I conclude that the number of firms expected to be negatively affected by a reduction in litigation costs appears to be reasonably small compared to the number of firms expected to be better off.

Therefore, whereas the bargaining game leads to an ambiguous prediction on the change in the number of agreements, combining the theoretical intuition of the model with some empirical figures I show it is possible to get an idea of the magnitude of the two effects. In particular, it seems reasonable to exect the policy exercise to lead to a reduction in the number of broad cross-license agreements that more than compensate the possible surge in persuasive litigation.

7 Conclusion

The existence of a patent thicket has led various economists to question the optimality of the current patent system (e.g. Gallini and Scotchmer (2002), Jaffe and Lerner (2004) and Shapiro (2001)) or even to propose the elimination of it (e.g. Quah (2006), Boldrin and Levine (2002) and Bessen and Maskin (2000)).

Signing broad cross-license agreements, some firms endogenously react to the patent thicket choosing not to enforce their intellectual property at all. Analyzing these contractual arrangements, I have shed some lights on the characteristics of these firms.

To uncover the incentives behind these contracts, I have developed a model of bargaining with learning in which firms litigate over their patent disputes if they do not agree upon a cross-license. The model predicts that the incentive to litigate decreases with firm investment in specific technology. More precisely, I have shown that whereas firms with low asset specificity prefer not to sign a cross-license agreement, firms with high sunk costs are better off cross-licensing their intellectual property. In addition, the model predicts that firms with intermediate levels of sunk costs will engage in inefficient "persuasive" litigation aimed at obtaining a better deal in a broad cross-license contract.

I have tested the predictions of the model using a novel dataset merging data on cross-license agreements, patent litigation and financial variables for firms in the semiconductor industry. Adopting a two-stage estimation strategy I have shown that the data provide strong support to the predictions of the bargaining game. More specifically, I have shown that whereas the presence of strategic interaction between two firms is mostly determined by their technological closeness, the choice between cross-license and litigation is uniquely determined by firms' capital intensities. Moreover, the empirical analysis confirms the existence of "persuasive" litigation among firms with intermediate values of capital intensity.

I have exploited the dataset to analyze the potential effects of a patent litigation reform as the one recently requested by a coalition of leading technology companies. Because of the skewed capital intensity distribution of semiconductor firms, I have concluded that a reform may induce a substantial reduction in the number of broad cross-license agreements.

The paper can be extended in various directions. Theoretically the model considers two firms only. Extending the framework to more than two players may help understanding what externalities cross-licensing implies, and what determines a network structure as the one observed in the semiconductor industry. Moreover, enlarging the number of players may lead to interesting results about the distribution of bargaining power and its effects on technology transmission (see Galasso (2007) for a theoretical treatment of bargaining power in these contractual settings).

Empirically it may be valuable to consider the possible effects of property right fragmentation on firms incentives to litigate. To construct a fragmentation index similar to those in Ziedonis (2004) and Noel and Schankerman (2006) will be crucial to understand this effect. Secondly, it would be valuable to perform an empirical analysis similar to the one of this paper to a different industry where innovation is less cumulative (as chemicals or pharmaceuticals) and where cross-licensing is more likely to be due to technological complementarities. Comparing the empirical evidence from these two settings may improve our understanding of cross-license agreements and may show how the very same contractual arrangements may be generated by completely different incentives.

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Appendix

Proofs

Proof of Proposition 1

In the absence of optimism, there will be agreement only if the duopolistic surplus exceeds the surplus from litigation: i.e $\alpha V - 2F \geq \overline{u} + \underline{u}(k)$. For low values of k this inequality is not satisfied and there is equality at $1 - \frac{4L}{F} + \frac{V(1-\alpha)}{F} = \underline{k}$.

Define now $V_t^i(m)$ as the continuation value of i at (m,t) and S_t as social surplus $S_t = V_t^1(m) + V_t^2(m)$. From Yildiz (2004) we know that S_t is deterministic and does not depend on m.

I define the agreement regime the case in which

$$\frac{\alpha V - 2F}{1-\delta} \geq \overline{u} + \underline{u}(k) + \delta S_{t+1}. \tag{9}$$

In this case the player chosen by the nature extracts the rent $\frac{\alpha V - 2F}{1-\delta} - \overline{u} - \underline{u}(k) - \delta S_{t+1}$. I define the no agreement regime the case in which (9) is not satisfied. In this case the rent extracted is zero. I can therefore define the rent extracted in period t as:

$$R_t = \max\left\{\frac{\alpha V - 2F}{1-\delta} - \overline{u} - \underline{u}(k) - \delta S_{t+1}, 0\right\}.$$

Moreover

$$V_t^i = p_t^i(m)\left[R_t + \overline{u} - \underline{u}(k)\right] + \underline{u}(k) + \delta E(V_{t+1}^i) = \sum_{s=t}^{\infty} \delta^{s-t}\left[p_t^i(m)\left(R_s + \overline{u} - \underline{u}(k)\right) + \underline{u}(k)\right]$$

where the second equality follows because the current continuation value is the infinite sum over expected future rents.

This can be re-written as

$$V_t^i(m) = p_t^i(m)\Lambda_t + \frac{\underline{u}(k)}{1-\delta}$$

and it implies that

$$S_t = (1+y_t)\Lambda_t + \frac{2\underline{u}(k)}{1-\delta}$$

where $\Lambda_t = \sum_{s=t}^{\infty} \delta^{s-t}\left(R_t + \overline{u} - \underline{u}(k)\right)$.

From the previous definitions it is possible to observe that in the agreement regime:

$$R_t = \frac{\alpha V - 2F}{1-\delta} - \overline{u} - \underline{u}(k) - \delta S_{t+1} = \frac{\alpha V - 2F}{1-\delta} - \overline{u} - \underline{u}(k) - \delta \left[(1 + y_{t+1})\Lambda_{t+1} + \frac{2\underline{u}(k)}{1-\delta} \right].$$

In addition the definition of Λ_t implies that $\Lambda_t = R_t + \overline{u} - \underline{u}(k) + \delta\Lambda_{t+1}$ and this condition can be used to obtain this difference equation:

$$\Lambda_t = \frac{\alpha V - 2F - 2\underline{u}(k)}{1-\delta} - \delta y_{t+1}\Lambda_{t+1}.$$

Notice now that a condition to have agreement is

$$\frac{\alpha V - 2F}{1-\delta} \geq \overline{u} + \underline{u}(k) + \delta S_t = \overline{u} + \underline{u}(k) + \delta(1 + y_t)\Lambda_t + \frac{2\delta\underline{u}(k)}{1-\delta}.$$

I can rewrite this condition as

$$\Lambda_t \leq \frac{\alpha V - 2F - 2\underline{u} - (\overline{u} - \underline{u}(k))(1-\delta)}{(1-\delta)\delta(1+y_t)} \equiv D_t$$

From Yildiz (2004) lemma 6, lemma 7 and lemma 8, we know that another condition to have agreement is

$$B_t \equiv \frac{(\alpha V - 2F - 2\underline{u}(k))}{(1-\delta)(1+\delta y_{t+1})} \leq \frac{\alpha V - 2F - 2\underline{u}(k) - (\overline{u} - \underline{u}(k))(1-\delta)}{(1-\delta)\delta(1+y_t)} = D_t.$$

This condition can be rewritten as

$$y_t - y_{t+1} \leq \frac{1-\delta}{\delta} - \frac{(\overline{u} - \underline{u}(k))(1-\delta)(1+\delta y_{t+1})}{(\alpha V - 2F - 2\underline{u}(k))\delta} \tag{10}$$

or as

$$(1-\delta)(\alpha V - 2F - \underline{u}(k) - \overline{u}) \geq (y_t - y_{t+1})\delta(\alpha V - 2F - 2\underline{u}(k)) + (\overline{u} - \underline{u}(k))(1-\delta)\delta y_{t+1}$$

that clearly describes the agreement trade-off. On the left hand side there is the rent lost with a delay in the agreement, on the right hand side there is the expected gain in future rent due to learning adjusted by the overestimated probability of being the patentee.

Let us rewrite (10) as:

$$y_t - y_{t+1} \leq \frac{1-\delta}{\delta} - A(k,\alpha)\frac{(1-\delta)(1+\delta y_{t+1})}{\delta}$$

The formula

$$A(k,\alpha)=\frac{(\overline{u}-\underline{u}(k))}{\alpha V-2F-2\underline{u}(k)}=\frac{\frac{1}{2}(V-F(1-k))}{2L-F(1-k)+\frac{\alpha V}{2}}$$

is what differentiate my model from the one of Yildiz (2004) in which the outside options $\overline{u}$ and $\underline{u}(k)$ are not present. It is easy to see that $A(k,\alpha)$ is a function decreasing both in k [12] and in α, therefore with an increase in capital intensity (higher k) the right hand side of (10) increases. Therefore an increase in capital intensity allows for agreement for higher values of $y_t - y_{t+1}$. Since $y_t - y_{t+1}$ is decreasing in t and approaches zero as $t \to \infty$ there exists some real number t_u such that $B_t \leq D_t$ if and only if $t \geq t_u$. In addition t_u is decreasing in k.

Using the formula for the beliefs we can characterize the value of k above which there is immediate agreement. Notice that

$$y_0 - y_1 = \frac{\Delta}{n} - \frac{\Delta}{n+1} = \frac{\Delta}{n(n+1)}.$$

The condition necessary to have immediate agreement is therefore:

$$\frac{\Delta}{n(n+1)} \leq \frac{1-\delta}{\delta} - A(k,\alpha)\frac{(1-\delta)}{\delta}(1+\frac{\delta\Delta}{n+1}). \tag{11}$$

Notice that k^* is defined as the value of k for which (11) holds with equality. I can re-write (11) as

$$z \leq \frac{1-\delta}{\delta}\left[1 - A(k,\alpha)\left(1+\delta y_1\right)\right] \equiv g(k,\alpha,\delta) \tag{12}$$

where $z = \dfrac{\Delta}{n(n+1)}$.

Notice that $A(\underline{k},\alpha) = 1$ and $A(1,\alpha) = \dfrac{V/2}{\alpha V/2 + 2L} > 1/2$.

Notice that $g(k,\alpha,\delta)$ is positive as long as

$$\delta \leq \frac{1-A(k,\alpha)}{A(k,\alpha)y_1} \equiv \overline{\delta}.$$

In this range, the function $g(k,\alpha,\delta)$ is a decreasing continuous function in δ with

$$\lim_{\delta\to 0} g(k,\alpha,\delta) = +\infty$$

and

$$\lim_{\delta\to\overline{\delta}} g(k,\alpha,\delta) = 0.$$

[12] It's derivative is negative as long as $\alpha V > 4L$ that satisfies our parameter restrictions.

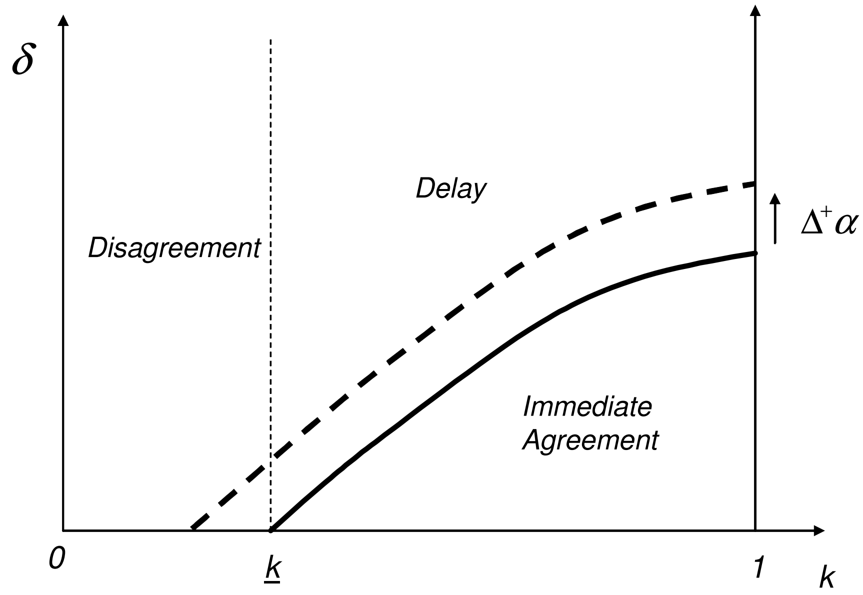

Figure 6: Markov Perfect Equilibrium

This result guarantees that for every $k > \underline{k}$ it is possible to find a discount factor $\widehat{\delta}$ for which immediate agreement arises as an equilibrium if $\delta \leq \widehat{\delta}$ (indeed notice that $\overline{\delta} = 0$ only if $1 = A(k, \alpha)$).

Finally because of the implicit function theorem it is possible to see that

$$\frac{d\widehat{\delta}}{dk} > 0$$

that proves Proposition 1.

Applying the implicit function theorem to (12) it is easy to see that $\dfrac{d\widehat{\delta}}{d\alpha} > 0$.

The following figure summarizes these results.

7.0.1 Derivation of the Ordered Probit Likelihood Function

Following Van De Ven and Van Praag (1981) and I am interested in the following likelihood function:

$$L = \prod_{CONTACT=0} P(\ y_1^* \leq 0) \prod_{OUTCOME=1} P(\ y_2^* < c_1 \ \wedge \ y_1^* > 0)$$
$$\prod_{OUTCOME=2} P(\ c_1 \ < \ y_2^* < c_2 \wedge \ y_1^* > 0) \prod_{OUTCOME=3} P(\ c_2 < y_2^* \ \wedge y_1^* > 0).$$

Assuming that u_1 and u_2 are bivariate standard normally distributed with correlation coefficient ρ and cumulative distribution Φ_2 it is easy to see that

$$P(\ y^*_{1ij} \leq 0) = P(x'_{1ij}\beta_1 + u_{1ij} < 0) = P(u_{1ij} < -x'_{1ij}\beta_1) = \Phi(-x'_{1ij}\beta_1).$$

Moreover

$$\begin{aligned} P(\ y^*_2 &< c_1 \wedge y^*_1 > 0) = P(u_2 < c_1 - x'_{2ij}\beta_2, u_1 > -x'_{1ij}\beta_1, \rho) \\ &= 1 - (1 - \Phi(c_1 - x'_{2ij}\beta_2)) - \Phi_2(c_1 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho) \\ &= \Phi(c_1 - x'_{2ij}\beta_2) - \Phi_2(c_1 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho). \end{aligned}$$

Similarly

$$\begin{aligned} P(\ c_1 &< y^*_2 < c_2 \wedge y^*_1 > 0) = \\ &= P(u_2 < c_2 - x'_{2ij}\beta_2, u_1 > -x'_{1ij}\beta_1, \rho) - P(u_2 < c_1 - x'_{2ij}\beta_2, u_1 > -x'_{1ij}\beta_1, \rho) \\ &= \Phi(c_2 - x'_{2ij}\beta_2) - \Phi_2(c_2 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho) - \Phi(c_1 - x'_{2ij}\beta_2) \\ &\quad +\Phi_2(c_1 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho). \end{aligned}$$

Finally notice that

$$\begin{aligned} P(\ c_2 &< y^*_2 \wedge y^*_1 > 0) = \\ &= 1 - \Phi(-x'_{1ij}\beta_1) - \Phi(c_2 - x'_{2ij}\beta_2) + \Phi_2(c_2 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho) \end{aligned}$$

Combining these results I obtain the formula for the likelihood function:

$$\begin{aligned} L &= \prod_{CONTACT=0} \Phi(-x'_{1ij}\beta_1) \prod_{OUTCOME=1} \left[\Phi(c_1 - x'_{2ij}\beta_2) - \Phi_2(c_1 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho)\right] \\ &\quad \times \prod_{OUTCOME=2} \left[\begin{array}{c} \Phi(c_2 - x'_{2ij}\beta_2) - \Phi_2(c_2 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho) - \Phi(c_1 - x'_{2ij}\beta_2) \\ +\Phi_2(c_1 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho) \end{array} \right] \\ &\quad \times \prod_{OUTCOME=3} \left[1 - \Phi(-x'_{1ij}\beta_1) - \Phi(c_2 - x'_{2ij}\beta_2) + \Phi_2(c_2 - x'_{2ij}\beta_2, -x'_{1ij}\beta_1, \rho)\right] \end{aligned}$$

Proof of Proposition 4

Recalling that $\underline{k} = 1 - \frac{4L}{F} + \frac{V(1-\alpha)}{F}$ it is easy to see that $\frac{d\underline{k}}{dL} < 0$.

Moreover, a total differentiation of (12) shows that $\frac{dk^*}{dL} < 0$ as well.

Table 1

Summary Statistics for Firm Pairings

	Mean	Median	Std Dev
Total Portfolio	788.92	133	1616.84
Portfolio Ratio	53.90	5.52	241.26
Patent Intensity	106.85	66.48	119.12
Average Capital Intensity	214.4	172.39	148.21
Capital Intensity Ratio	3.17	2.09	3.34
Minimum Employment	840	289	2125
TECH	0.21	0.14	0.24
LINK	0.03	0.00	0.22
SIC	0.20	0.00	0.27
BSVSIC	0.56	0.70	0.40
Average Sunkness Index	1.07	1.00	0.78

Summary Statistics for 4465 firm pairings. TECH: measure of technologial distance. LINK: measure of technological overlapping. BSVSIC and SIC: measures of product market similarity.

Table 2

Measures Correlation

	TECH	LINK	SIC	BSVSIC
TECH	1.00			
LINK	0.27	1.00		
SIC	0.10	0.09	1.00	
BSVSIC	0.10	0.02	0.13	1.00

Correlation among technological and product market distance measures.

Table 3

Comparison of Means: CONTACT

	No Contact	**Contact**
Total Portfolio	766.63	2930.39
	(23.71)	(480.75)
Portfolio Ratio	54.01	42.68
	(3.64)	(14.33)
Patent Intensity	106.32	157.72
	(1.78)	(24.09)
Average Capital Intensity	213.94	257.94
	(2.23)	(20.58)
Capital Intensity Ratio	3.18	2.11
	(0.05)	(0.17)
Average Sunkness Index	1.06	1.70
	(0.01)	(0.11)
Minimum Employment	820.05	2769.78
	(31.50)	(542.96)
TECH	0.21	0.54
	(0.00)	(0.03)
LINK	0.02	0.55
	(0.00)	(0.17)
SIC	0.20	0.32
	(0.00)	(0.03)
BSVSIC	0.56	0.60
	(0.00)	(0.05)

Mean comparison among parings with and without contact. Contact=1 if the firm pair discloses litigation or cross-license; Contact=0 otherwise. Standard Errors in brackets.

Table 4

Comparison of Means: OUTCOME

	Litigation Only	Litigation & CL	CL only
Total Portfolio	1652.09	3738.37	4829.75
	(599.50)	(847.74)	(1074.45)
Portfolio Ratio	26.10	61.28	51.07
	(11.64)	(36.58)	(22.78)
Patent Intensity	151.30	178.87	133.09
	(41.77)	(37.61)	(27.68)
Average Capital Intensity	197.23	262.54	415.62
	(21.72)	(27.21)	(59.36)
Capital Intensity Ratio	1.88	1.83	3.28
	(0.17)	(0.20)	(0.63)
Average Sunkness Index	1.29	2.00	2.25
	(0.16)	(0.16)	(0.25)
Minimum Employment	1497.27	3476.56	4855.62
	(414.66)	(877.50)	(2185.93)
TECH	0.57	0.48	0.59
	(0.05)	(0.06)	(0.06)
LINK	0.30	0.78	0.80
	(0.10)	(0.38)	(0.55)
SIC	0.29	0.34	0.34
	(0.04)	(0.06)	(0.09)
BSVSIC	0.48	0.70	0.76
	(0.09)	(0.07)	(0.08)

Litigation Only: 22 pairings that litigated and did not cross-license. Litigation and CL: 16 pairings that cross-license after litigation. CL only: 8 pairings that cross-license without litigation. Std Errors in brackets.

Table 5

Probit Regression: CONTACT					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Total Portfolio (x1000)	**0.09 (0.02)****	0.14 (0.06)*	**0.09 (0.02)****	**0.07(0.02)****	**0.13 (0.04)****
Portfolio Ratio(x1000)					-0.35 (0.67)
Total Portfolio^2(x1000)		-0.06 (0.39)			
Average Sunkness Index				0.15 (0.12)	
Average Capital Intensity (x1000)					-0.53 (0.60)
Capital Intensity Ratio					-0.06 (0.03)
Minimum Employment					-0.01 (0.02)
Patent Intensity (x1000)					-0.01 (0.77)
TECH	**1.30 (0.19)****	**1.29 (0.20)****	**1.28 (0.19)****	**1.23 (0.23)****	**1.29 (0.26)****
LINK	**0.33 (0.06)****	**0.35 (0.07)****	**0.31 (0.06)****	**0.34 (0.07)****	**0.32 (0.11)****
SIC			0.33 (0.17)		
BSVSIC					-0.16 (0.13)
Constant	-2.96 (0.12)**	-2.99 (0.12)**	-3.03 (0.13)**	-3.12 (0.12)**	-2.60 (0.18)**
Number of Observations	4465	4465	4465	4465	4465
Log Pseudolikelihood	-205.17	-204.91	-204.30	-203.65	-201.72
Pseudo R2	0.199	0.200	0.203	0.205	0.212

Probit Regression, dependent variable CONTACT=1 if litigation or cross-license registered for a firm pairing. Robust standard erroros in brackets. ** significant at 1% * significant at 5%.

Table 6

Probit Regression: Total Portfolio Marginal Effects

	Mean	Median	90th Percentile
Total Portfolio ($x10^4$)	**0.001**	**0.001**	**0.001**
TECH	**0.18**		
LINK	**0.004**		

Maringal Effects evaluated of CONTACT probit. In column (1) marginal effects are evaluated at the mean for all three variables, in column 2 and column 3 TECH and LINK are mantained at their mean value and Total Portfolio is at the Median and 90th percentile

Table 7

Tobit II Regression: OUTCOME

	(1)	(2)	(3)	(4)
Average Capital Intensity (x1000)	**5.08 (1.71)****	**4.99 (1.70)****	**5.42 (1.49)****	
Average Sunkness Index				**0.88 (0.21)****
Total Portfolio (x1000)		0.02 (0.10)	-0.01 (0.08)	-0.01 (0.08)
SIC		0.72 (0.95)		0.78 (0.65)
BSVSIC			0.92 (0.61)	
Minimum Employment		1.71 (6.77)	-0.29 (8.88)	3.83 (7.75)
Constant 1	1.86	2.68	2.81	2.12
Constant 2	0.61	1.38	1.50	0.91
Ro	-0.26 (0.32)	-0.06 (0.50)	-0.14 (0.51)	-0.40 (0.35)
First Stage				
Total Portfolio (x1000)	0.09 (0.02)**	0.09 (0.02)**	0.09 (0.02)**	0.09 (0.02)**
TECH	1.28 (0.18)**	1.30 (0.19)**	1.29 (0.24)**	1.28 (0.23)**
LINK	0.34 (0.06)**	0.33 (0.06)**	0.34 (0.12)**	0.34 (0.11)**
Number of Observations	4465	4465	4465	4465
Log Pseudolikelihood	-244.09	-243.65	-242.55	-243.13

Tobit II Maximum Likelihood Regression. First Stage: probit on CONTACT. Second Stage: Ordered Probit on OUTCOME. OUTCOME =1 if the pairing resolves dispute by litigation and not cross-license. OUTCOME=2 if cross-license is delayed. OUTCOME=3 if immediate cross-license. Ro =corelation between first and second stage errors. Robust standard errors adjusted for Name Clusters reported in parenthesis. * significant at 5% **significant at 1%.