Cross-License Agreements in the Semiconductor Industry: Waiting to Persuade?

Alberto Galasso*

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Abstract

In various industries cross-licensing is considered a useful method to obtain freedom to operate and to avoid patent litigation. In this paper we study the trade-off between litigating and cross-licensing that firms face to protect their intellectual property. We present a dynamic model of bargaining with learning in which firms' decision to litigate or cross-license depends on their capital intensity. In particular the model predicts that where firms' capital intensity is higher their incentive to litigate and delay a cross-license agreement is lower. Using a novel dataset on the US Semiconductor Industry we obtain empirical results consistent with those suggested by the model.

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 new technology. In fact, 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 down production 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

*Department of Economics, the London School of Economics. Email: A.Galasso@lse.ac.uk. I thank Andrea Prat and Mark Schankerman for their guidance and continuous help. I also thank Philippe Schmidt-Dengler, John Moore, Michele Piccione and Giacomo Rodano for helpful comments.

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

arrangements enabling firms to cut through the thicket have appeared. The objective of this paper is to analyze one of these arrangements: 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.

To study these agreements we focused on the Semiconductor Industry. Previous studies have pointed out how severe the thicket is in this sector (Grindley and Teece (1997), Hall and Ziedonis (2001), Ziedonis (2003)). In fact, this industry has registered a continuous and steady pace of progress with the number of transistors on a chip doubling every year since the invention of the integrated circuit. Recent estimates of the Semiconductor Industry Association predict that this exponential rate of progress will continue at least until 2020[3]. In addition to this cumulative innovation, the industry is characterized by the fact that 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), Ziedonis (2004)).

Our analysis of the semiconductor industry is based on a new dataset we compiled based on their disclosure of patent litigation and licensing agreements in the Security Exchange Commission filings. We first identify the universe of 95 publicly-traded US firms whose principal line of business is semiconductor and related devices (SIC 3674) and then compiled a database of these firm patent portfolios, their financial variables and their licensing and patent litigation activity.

Two stylized facts emerge from these data. First, firms seems to resolve their intellectual property disputes following one of three recurrent patterns:

1. either they litigate about some specific intellectual property (IP) and they terminate their litigation with a settlement or a court ruling concerning only these specific IPs;

2. or they litigate about some specific IP and terminate the litigation with a broad cross-license agreement involving all their patents and their future innovations;

3. or they sign a broad cross-license agreement without any previous litigation.

Second, the sorting among these three options seems to be strongly correlated with firms' capital intensity. This correlation can be observed in Figure 1.

[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).

[3] Semiconductor Industry Association 2005 Annual Report.

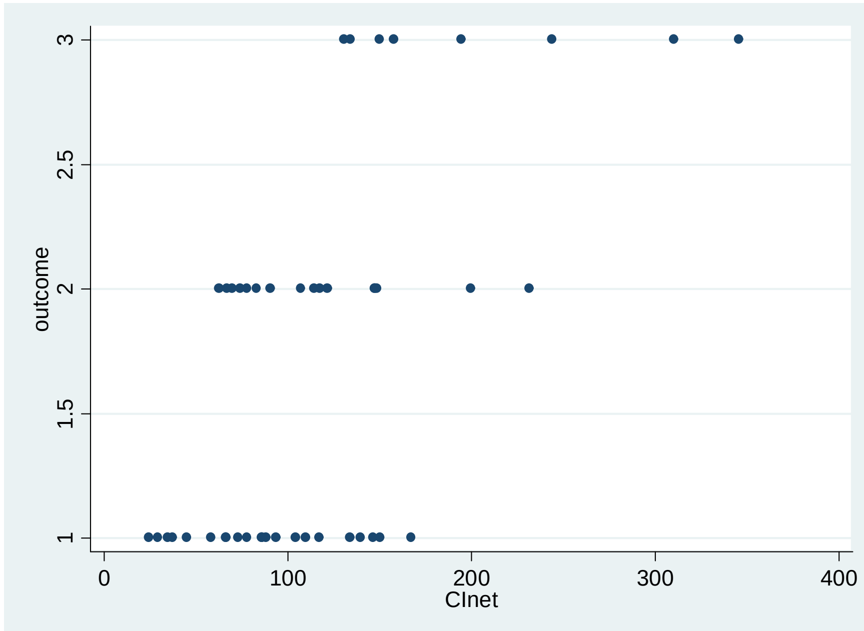

Figure 1: Capital Intensity and Cross-Licensing

In this graph we scattered average capital intensity (measured as ratio plant and equipment to employees) and dispute resolution technique for firm pairings disclosing litigation or cross-licensing between 1990 and 2004. It can be noticed that firm pairings with low average capital intensity litigate without signing a cross-license agreement (Outcome 1), those with intermediate average capital intensity litigate before cross-licensing (Outcome 2) and finally those with high average capital intensity cross-license immediately.

To explain these stylized facts we develop a model of bargaining with learning that exploits the theoretical results in Yildiz (2003) and Yildiz (2004). In our theoretical framework two firms bargain over a cross-license agreement having incomplete information on their future use of their counterpart patents. Each of them is optimistic in the sense that it believes that its counterpart is under-estimating its future patent infringements.

Delaying the agreement allows each firm to learn how frequent its counterpart infringements will be and - as optimism disappears- to obtain better terms in the cross-license agreement. Nevertheless, to wait is costly because it implies that disputes are going to be solved by litigation. In fact, if firms litigate and the court finds the patent valid, the infringer will have to shut production down sustaining a cost that depends on its capital intensity: the higher the capital intensity of the infringing firm the higher its loss due to former specific investments.

In this context the model predicts an equilibrium behavior similar to the one plotted in Figure 1. Firms with low capital intensity will prefer to solve their disputes litigating because for them the cost of litigation is so low that sharing the market with a cross-license is not profitable. Firms with intermediate capital intensity will find cross-licensing an efficient solution but will delay the agreement to persuade their counterparts and obtain better deals. Finally, firms with high capital intensity cross-license immediately because for them the cost of litigation is so high that it is not worth waiting to persuade.

Having developed this model we test empirically its predictions using our dataset. For each firm pairing among the 95 firms in our sample we computed various measures of product market competition and technological similarity. We then used these measures and other financial variables to analyze which firm parings were more likely to disclose a patent litigation or cross-license agreements. Not surprisingly we found that technological closeness and size of the portfolios are the main determinants of observed interactions. Exploiting this result we used a two-stage Heckman procedure to verify, once a dispute has occurred, what determines the choice between the various dispute resolution techniques. In all our regressions capital intensity is significant at the .01 level and we find no other variable statistically significant.

Various strand of literatures are somewhat connected to our research. Theoretically there are various 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. Indeed private information can induce delay due to signalling, screening or attrition purposes. Moreover, both games with simultaneous offers as Perry and Reny (1993) and in models with more than two players as Cai (200) there can be equilibria with delays. Another application of Yildiz's framework can be found in Wantanabe (2005): a model of medical malpractice litigation in which patients and hospitals learn while bargaining over a settlement.

The idea that delay in bargaining can be caused by excessive optimism due to the lack of common prior was previously noted by legal scholars (see Landes (1971), Posner (1972) and Lanjouw and Lerner (1998) for a survey). In this literature litigation is seen as a two-period game in which the two parties decide whether to settle in the first period or to go to a costly trial by a judge or an arbitrator in the second period. Parties have optimistic beliefs about the judgment and the greater the divergence in their expectations the higher the probability of litigation.

Lanjouw and Schankerman (2001) and Lanjouw and Schankerman (2004) provide an extensive treatment of patent litigation and find that frequency of legal disputes is strongly correlated with a variety of characteristics of innovations and they owners. In particular they show that patentees are more likely to go to court to protect patents that form the base of a cumulative chain of innovations, that reputation building plays a role in the decision to litigate and that litigation risk is much higher for patents owned by individuals and firms with small patent portfolios.

Analyzing litigation in the Semiconductor Industry Ziedonis (2003) noticed a high propensity of small firms to be involved in patent-related lawsuits and found that the average litigation rate of specialized design firms is high and is more than twice that of manufacturers.

The paper is organized as follows. In Section 2 we present the infinite horizon model and the main proposition. In Section 3 we use a simplified two-period version of the model to obtain testable predictions on the effect of product market competition and of asymmetries in the capital intensity. In Section 4 we present our data. In Section 5 we describe some non–parametric statistics of our dataset. In Section 6 we present the econometric analysis. Section 7 concludes.

2 The Model

In this section we develop a model in which two firms bargain over a cross-license agreement with litigation as outside option. 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).

We consider a setting with two firms $N = \{1, 2\}$ and an infinite stream of innovations. Each innovation is going to be embedded in a product at a cost of F. We assume that a fraction $k \leq 1$ of this production cost is sunk. The innovation gives revenue equal to V for one period only, then it 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 he is the unique user of the innovation are $V - (1-k)F$. If infringer and patentee both use the innovation each of them obtains a profit of $V/2 - (1-k)F$[4]. 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 we assume that with probability 1/2 the patent is found to be valid and with probability 1/2 it is not.

Therefore the patentee expected payoff is:

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

Conversely, the expected payoff for the infringer is:

$$\underline{u} = \frac{1}{2}(1-k)F + \frac{1}{2}(\frac{V}{2} - (1-k)F) - L \quad (2)$$

In modeling the payoff of the infringer we assumed that with probability 1/2 the patent is invalid and he enjoys the duopoly profit and with probability 1/2 the patent is valid and he can recover only the non-sunk part of his costs. In the remaining part of the paper we will refer to k as capital intensity because capital intensive firms are more likely to sustain sunk costs and to invest in specific technology that either cannot be used if the production cannot take place or are costly diverted

[4]For simplicity we assume here that total revenue remain constant. In Section 3.2 we relax this assumption.

to other activities. The fact that the cost associated with stopping production or varying production processes increases with firm' capital intensity has been already emphasized in the literature. In particular Shapiro (2001) stresses how the hold-up problem is more serious for large-scale manufacturers and Hall and Ziedonis (2001) describe how capital-intensive semiconductor firms engage in "patent-portfolio races" to prevent litigation. [5].

Firms discount future with a discount factor $\delta < 1$. We 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) we assume that firms do not know ρ and they have two different priors about it. We 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 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 valid in our model: first a player's equilibrium payoff is the present value of all rents he expect to extract when he offers in the future, second a player i becomes better off in equilibrium whenever each player comes to believe that i has higher probability of recognition in the future.

We 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 future duopolistic profits[6]. If the infringer accepts this offer the game ends and the firms share 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. Players observe who is chosen, update their beliefs and the game proceeds with an infinite horizon. The actual game tree is specified in the following Figure 2.

[5] In addition, Ziedonis (2004) observes that the average litigation rate for is lower for big manufacturers.

[6] We do not consider more sophisticated licensing mechanisms as those presented in Kamien and Tauman (1986,2002). In our data, we 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". DoJ (1995).

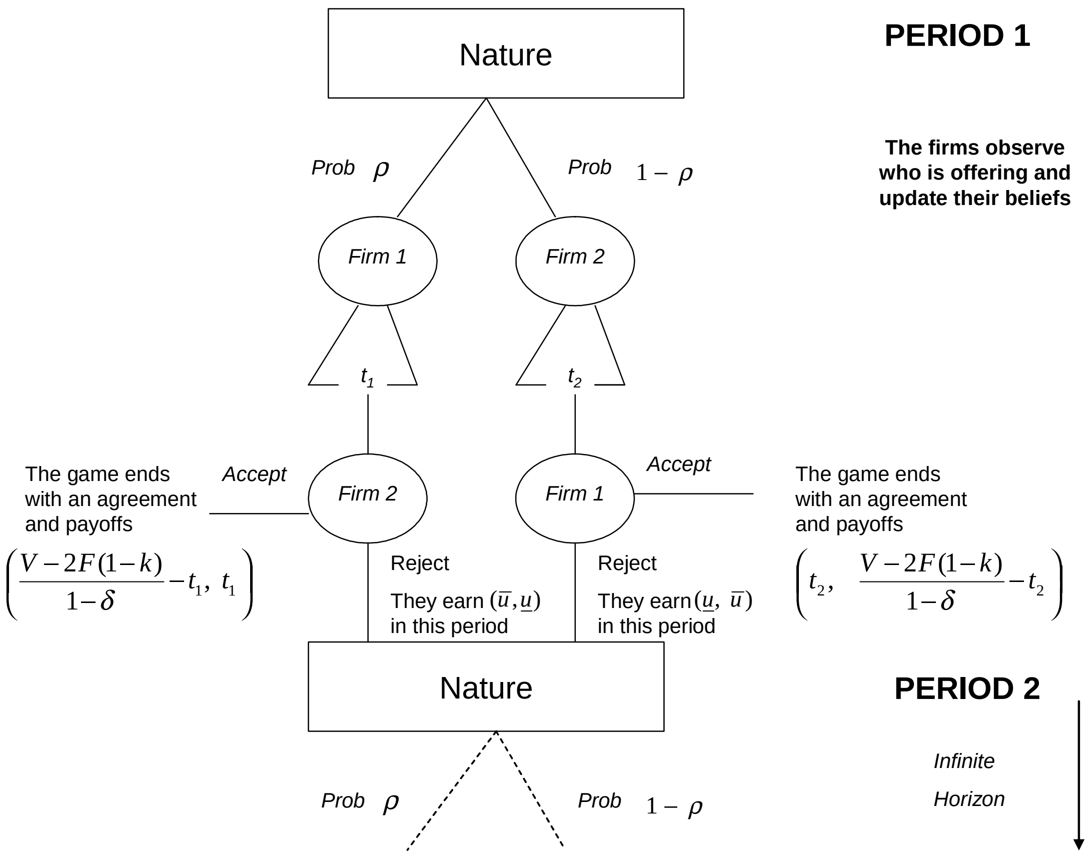

Figure 2: Game Tree

To study this infinite horizon bargaining game we need to assume some restriction on players' beliefs. Following Yildiz (2003) we assume that they have beta distributions. Fixing any positive integers $\overline{m}_1$, $\overline{m}_2$ and n with $1 \leq \overline{m}_2 \leq \overline{m}_1 \leq n-2$, we 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. A Yildiz (2004), we 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 he will offer with probability $p_t^j(m)$ which is higher than $1-p_t^i(m)$ as we will see in a moment.

As explained above, this means that player i thinks that j is optimistic. Since each player thinks that the other player is optimistic, we will say that the players are optimistic at (m, t).

Let us 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:

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

Since $y_t(m) > 0$, the players are indeed optimistic at each (m, t). Moreover y_t is deterministic: it does not depend on m and therefore we can suppress m from our notation. This is due to the assumption that n is the same in both distributions and it simplifies the analysis dramatically. Note that as t gets large firms' beliefs converge and firms learn the actual ρ.

We assume the following parameter restriction:

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

The following proposition characterize the unique Markov perfect equilibrium of this infinite horizon game in which player strategies only depend on how many times a player has been recognized.

Proposition 1 *For $k \leq 1 - 2L/F \equiv \underline{k}$ litigation is efficient and there is never a cross-license agreement. For $k \geq \underline{k}$ 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 $k^* \geq k \geq \underline{k}$.*

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.

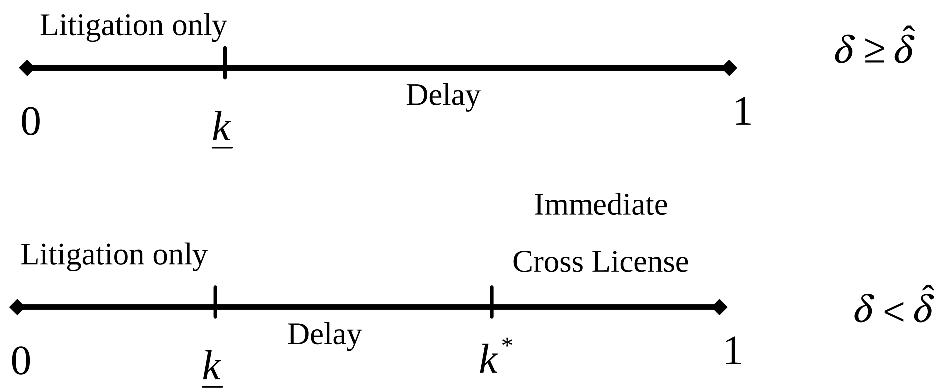

Figure 3: Equilibrium Outcomes

The trade-off leading to this result is quite intuitive. When a player receives an offer he believes that his counterpart is overestimating his bargaining power and offering too little. This encourages him to reject the offer and to wait some periods in order to let the other player observe his true bargaining power and to obtain better terms. Nevertheless waiting is costly and its cost depends both on firms capital intensity and on the discount factor. As in Yildiz (2003;2004) to delay the agreement is more costly if the discount factor is low and firms are impatient but in our model the cost of delay depends on the capital intensity as well. Indeed the litigation payoff is lower the higher the capital intensity of the firm. Therefore as capital intensity increases the incentive to wait is reduced and for k large enough it disappears.

3 Insights from the two period game

In the previous section we presented an infinite horizon model in which firms could learn about their relative bargaining power before signing a cross license agreement. Nevertheless learning was costly and its cost (increasing with capital intensity) generated a trade-off resulting in an optimal level of delay. In this infinite horizon framework it was possible to disentangle the two main components that were determining the length of the delay: the cost of learning expressed as the size of the outside option and the benefit of learning described as the speed with which beliefs converged to the true state of nature.

In this section we explore some extensions of the model simplifying the setting to a two period game. As we will see, in this simpler environment most of the insights of the general model will still be valid. Nevertheless there is an extreme form of learning that takes place in the last period in which one of the two parties obtains complete bargaining power and makes a take it or leave it offer to the counterpart. In particular, as Yildiz (2003) points out: whereas in the two period model optimism per se can generate delay, in the infinite-horizon model optimism generates delay only if combined with learning.

Our two period game proceeds as follow. In the first period nature selects one of the two players to make an offer to the counterpart. For simplicity we assume absence of discounting. Without loss of generality let us assume that firm 1 is the one making this offer. The two players will observe nature selection and update their beliefs. In particular firm 1 will assign posterior probability p_1 to making an offer next period and firm 2 will assign probability p_2 to making an offer in the second period. Firm 1 will offer to firm 2 a share of the two period duopolistic surplus i.e. a share of $2(V - 2F(1-k))$. If firm 2 rejects the offer the two firms obtain the outside options (1) and (2) for that period and then nature chooses the second period patentee. In the second (and final) period the chosen party makes a take it or leave it offer to the counterpart on a split of $V - 2F(1-k)$ and if there is disagreement the two parties obtain the outside options (2) and (1).

As usual we solve the game using backward induction. In the second period firm 2 obtains $V - 2F(1-k) - \underline{u}$ if chosen or $\underline{u}$ if firm 1 will be chosen. Therefore the offer of firm 1 that will make firm 2 indifferent between accepting or rejecting will be:

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

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

$$2(V - 2F(1-k)) - 2\underline{u} - p_2(V - 2F(1-k) - 2\underline{u}) \geq \overline{u} + \underline{u} + p_1(V - 2F(1-k) - 2\underline{u})$$

or

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

where the last inequality follows by replacing the outside options with their definitions. The basic intuition is that firms are going to delay the agreement if optimism is larger than a threshold $y(k)$.

Notice that :

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

that is positive because $V \geq 4L$ has been assumed in (3). The function $y(k)$ describes the level of optimism required to delay the agreement and this level is increasing in k because as k gets large waiting becomes more costly. As depicted in Figure 4 given an initial value of y we have that for low values of k there is no litigation for intermediate values there is delay and for high values there is immediate agreement. More precisely, while for low values and high values of capital intensity the choice between litigation and cross licensing is carried out efficiently, for intermediate values there is inefficient delay.

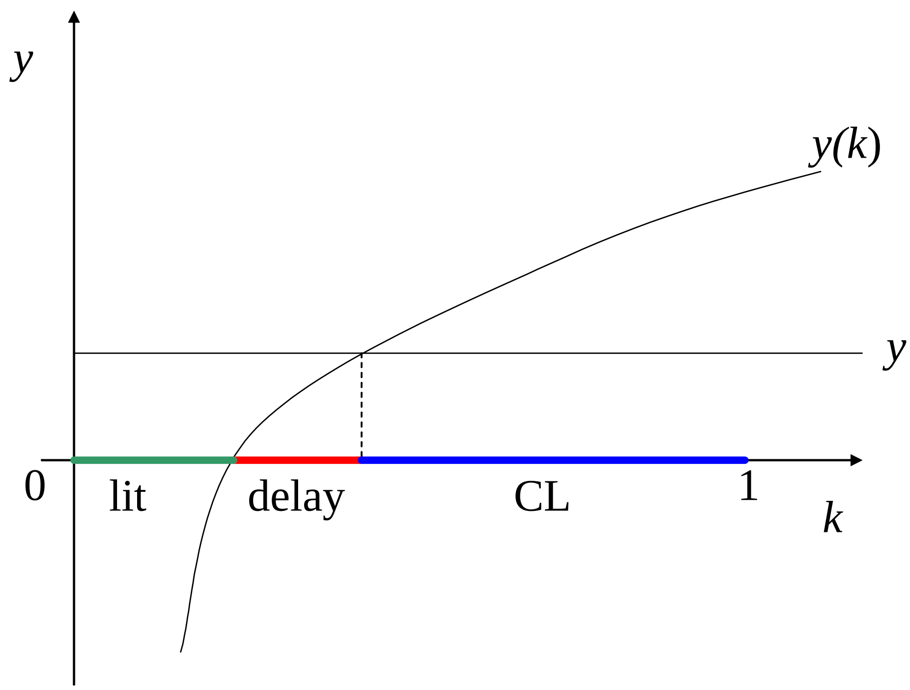

Figure 4: Equilibrium in the two-period game

3.1 Product Market Competition

We extend the previous model allowing the monopoly use of an innovation to generate a level of profit strictly higher than the duopoly use. To this end we denote as αV the total revenue generated by the duopolist with $\alpha < 1$. Nevertheless we keep assuming that $\alpha V - 2F \geq 0$ that is there is enough surplus to accommodate two duopolists. With a reasoning similar to the one conducted above we can show that in this setting the condition that has to be satisfied to have immediate agreement can be written as:

$$\frac{2L - F(1-k) - \frac{V}{2}(1-\alpha)}{\frac{\alpha V}{2} - 2F + 2kF + 2L} \equiv y(k, \alpha) \geq y.$$

It is easy to see that:

$$sgn\left\{\frac{dy(k,\alpha)}{d\alpha}\right\} = sgn\left\{\frac{V}{2} - F(1-k)\right\}$$

that is always positive because of assumption (3)

In addition we have that:

$$\frac{d^2y(k,\alpha)}{d\alpha dk} = \frac{VF}{2}\frac{\alpha V + 2F - 2kF + 2L - 2V}{(\alpha V - 2F + 2kF + 2L)^3} < 0.$$

From the two previous results it follows that an increase in product market competition moves $y(k)$ to the left and makes it steeper. We conclude that product market competition reduces the likelihood of both cross-licensing and delay. Therefore this simple exercise gives us the following testable prediction:

Lemma 2 *An increase in product market competition reduces the likelihood of cross-licensing. For capital intensive firms this effect should be smaller in magnitude.*

The intuition behind this result is quite simple. A lower level of α reduces both the size of the cake and the outside option. Nevertheless the reduction in the outside option is lower (it occurs only if the patent is invalid) therefore product market competition renders more attractive litigating rather than signing a cross license agreement. The effect on capital intense firm is smaller because the reduction in the size of the cake necessary to render litigation more appealing has to be larger when litigation is more costly.

3.2 Asymmetry in Capital Intensity

Let us call k_1 and k_2 the capital intensity of the two firms. Differently from the previous analysis we have now to consider both the case in which firm 1 is chosen to offer in period one and the event in which firm 2 is chosen. Nevertheless it is important to notice that according to Yildiz (2005) the total level of optimism at the second period does not depend on the identity of the firm chosen. If firm 1 offers in the first period then there is going to be immediate agreement if:

$$\frac{V - 2F - \overline{u}(k_1) - \underline{u}(k_2)}{V - 2F - \underline{u}(k_1) - \underline{u}(k_2)} > y.$$

Conversely if firm 2 is making the offer the condition becomes:

$$\frac{V - 2F - \overline{u}(k_2) - \underline{u}(k_1)}{V - 2F - \underline{u}(k_1) - \underline{u}(k_2)} > y.$$

We conclude that ex-ante we should expect to observe cross licensing if

$$g(k_1,k_2,\rho)\equiv\rho\frac{V-2F-\overline{u}(k_1)-\underline{u}(k_2)}{V-2F-\underline{u}(k_1)-\underline{u}(k_2)}+(1-\rho)\frac{V-2F-\overline{u}(k_2)-\underline{u}(k_1)}{V-2F-\underline{u}(k_1)-\underline{u}(k_2)}>y.$$

Replacing the outside options with their definition the above equation can be re-written as:

$$g(k_1,k_2,\rho)\equiv\rho\frac{2L-F(1-k_2)}{\frac{V}{2}-2F+(k_1+k_2)F+2L}+(1-\rho)\frac{2L-F(1-k_1)}{\frac{V}{2}-2F+(k_1+k_2)F+2L}>y.$$

From the above expression we obtain the following testable lemma.

Lemma 3 *An increase in capital intensity of the party with lower bargaining power increases the likelihood of cross licensing.*

Proof. Notice that

$$\frac{dg(k_1,k_2,\rho)}{dk_1}>0$$

only if

$$(1-\rho)\left(2L-2F+\frac{1}{2}V+F\left(k_1+k_2\right)\right)-\rho\left(2L-F\left(1-k_2\right)\right)-(1-\rho)\left(2L-F\left(1-k_1\right)\right)>0$$

that occurs if

$$\frac{V-F+Fk_2}{4L-2F+V+2Fk_2}>\rho. \tag{4}$$

It is easy to see that the left hand side is always greater than 0.5. Therefore if $1/2>\rho$ then an increase in k_1 renders more likely to observe a cross license agreement. In addition, computing $\frac{dg(k_1,k_2,\rho)}{dk_2}$ it is easy to observe that $\frac{dg(k_1,k_2,\rho)}{dk_1}>\frac{dg(k_1,k_2,\rho)}{dk_2}$ only if $1/2>\rho$. ■

Also in this case the intuition is quite straightforward. If two firms have different capital intensity the relevant capital intensity to be considered is the one of the firm with higher likelihood to be an infringer because it is the one that will be more likely to sustain the infringement cost. In addition, from the results of lemma 3 it is also possible to observe a counter-intuitive result: if the bargaining power of firm 1 is very large (condition (4) does not hold) then an increase of its capital intensity reduces the likelihood of a cross-license agreement. The intuition is that an increase in k_1 has two opposite effects: it increases the share requested by firm 2 (therefore inducing firm 1 to delay the agreement) and it renders litigation more costly for firm 1 (inducing firm 1 not to delay the agreement). For ρ large enough the first effect dominates. In the following Sections we test empirically the predictions of the model.

4 Data

Following Hall and Ziedonis (2001), we identified from Compustat the universe of firms whose principal line of business is semiconductor and related devices (SIC3674) who have data from 1998 to 2003. We then matched these firms with data of the NBER Patent Data file obtaining information on patent activity of these firms from 1963 to 2002. We restricted our sample to firms having some patenting activity after 1988 and we obtained a sample of 95 companies.

We obtained information on cross license agreements from the U.S. Security and Exchange Commission fillings from 1990-2004. In various filings firms are requested to disclose information on agreements involving their intellectual property. We report the requirement as expressed in the SEC guidelines to file Form 1.A[7]:

> *"Indicate the extent to which the Company's operations depend or are expected to depend upon patents.... including any use of confidentiality agreements, covenants-not-to-compete and the like. Summarize the principal terms and expiration dates of any significant license agreements......."*.

Examining the documents that public companies are required to file with the Commission we identified 24 broad cross license agreements among the firms in our sample. We define a **broad cross license** agreement as an agreement in which firms either cross licensed their entire patent portfolio (20/24 agreements) or they cross-licensed patents in some extensive technology group (e.g. memory devices). Some filings indicate only the existence of the contract others are more accurate disclosing terms and financial conditions. As an example we report an extract from the Form 10-K deposited in March 2005 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.*"

Only 24 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 from 1998 to 2002. Surprisingly, we found that the links created by cross-license agreements between firms are not completely random. Firms appears to be organized in two well defined star networks one with centre on Texas Instruments Inc. and another one

[7]See www.sec.gov/about/forms/secforms.htm for additional information on SEC filings.

with a core formed by four companies: Intel Corporation, Broadcom Corporation, National Semiconductor Corporation and Agere Systems Guardian Corporation. The following figure clearly illustrates the pattern observed.

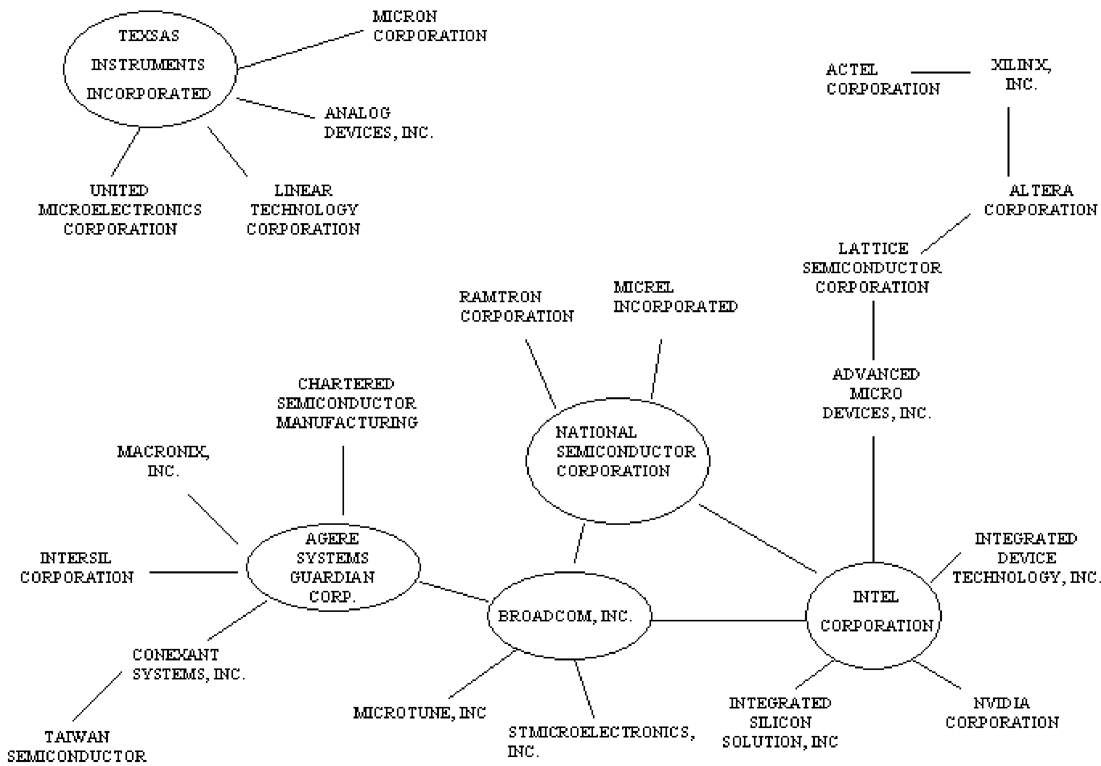

FIGURE 5: Cross-License Agreements in the Semiconductor Industry

In addition, from the SIC filings, we obtained data on patent litigation for the period 1990-2004 among firms in the sample. To this end we defined 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. We registered 38 cases of **patent litigation** among firm pairs in the sample.

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

[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.

To measure **product market distance** we 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 we identified 23 broad product categories (listed in the Appendix). Combining this information with data obtained from firm catalogs we 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 we computed the **SIC** distance as in Bloom, Schankerman and Van Reenen (2004) (henceforth BSV):

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

Secondly we exploited data from the BSV paper. We obtained sales of the firms in 7 4-digit SIC codes lines of business. We take the average share of sales per line of business within each firm over the period 1993-2000. We let $S_i = (S_{i1}, ...S_{i7})$ denote the distribution of sales of firm i across SIC codes. Following BSV we 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 SIC codes.

The **technological correlation** is measured using the 426 technology classes (N-classes) provided by the USPTO. Following Jaffe (1988) and BSV (2004) we 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 we constructed a measure of **linkages** between firms using the NBER Citation Data file. For each firm pair ij we computed the percentage of patents in the portfolio of i citing a patent of firm j and the percentage of patents in the portfolio of firm j citing a patent of firm i. More formally our index is:

$$LINK_{ij} = 0.5 \frac{\text{\# patents of } i \text{ citing } j}{\text{\# patents of } i} + 0.5 \frac{\text{\# patents of } j \text{ citing } i}{\text{\# patents of } j}.$$

It is important to note how our LINK measure differs from our 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 proxi 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.

From Compustat we obtained information on **capital intensity**. As Hall and Ziedonis (2001) we measured capital intensity as the ratio of plant and equipment to employees of each firm in year 2002. In addition for all firm pairings we considered the asymmetry between the two capital intensities computing the **ratio** (max/min) between the indexes. Both average and ratio have been calculated for the gross figure of property plant and equipment and for the net figure (i.e. subtracting accumulated depreciation).[9]

As previously discussed, Hall and Ziedonis (2001) justify the use of this capital-labor ratio as a proxy for cost involved with halting production. Conducting field interviews and analyzing data from the Integrated Circuit Engineering Corporation, they not only show that the cost of a new semiconductor fabrication plant is very large (in 1998 it was estimated as more than $1.5 billion) but also that it has increased (and is expected to keep increasing) over time whereas fabrication facility expected life span has decreased. Following both these evidences and the informal discussion in Shapiro (2001) we use firm capital intensity as an indicator of its cost in halting production.

5 Descriptive Statistics

In this Section we present summary statistics for the main variables used in our empirical estimation.

First we describe the distribution of patent portfolios and capital intensity across the 95 firms of our sample. The distributions of these two variables appear quite skewed to the left. The average size of the portfolios in our sample is 394.46 patents with a standard deviation of 1155.37. Nevertheless the median portfolio has only 42 patents. In Figure 6 we plot the portfolio distribution and we can observe that 54 firms obtained less than 50 patens in the period 1988-2000 whereas 9 firms patented more than 1000 innovations during the same period.

[9] Compustat offers information on machinery and equipment as well. Despite this information being closer to what we would like to measure we decided not to use it because there were too many missing values.

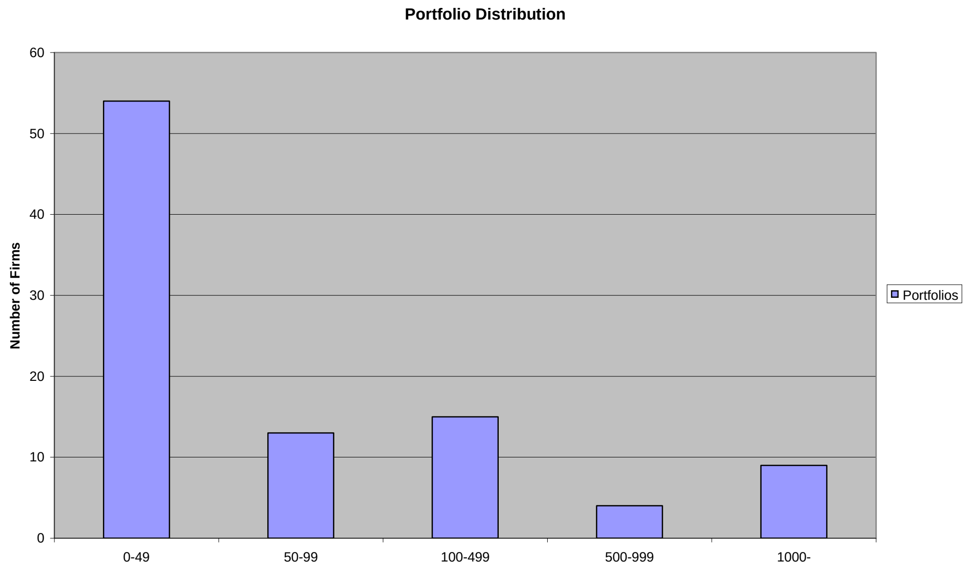

Figure 6: Portfolio Distribution

In Figure 7 we plot the distribution of capital intensity. On average a firm possesses property plant and equipment for 206,440 dollars per employee ($96,413 net of amortization) with a standard deviation of 181,430. The median firm has plant and equipment for 151,400 dollars per employee ($58,818 net of amortization).

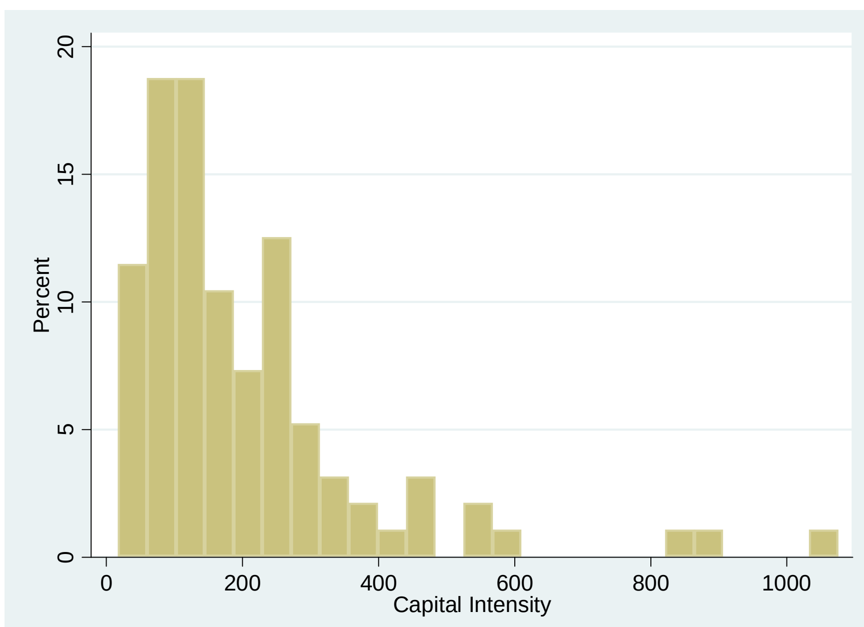

Figure 7: Capital Intensity Distribution

For a large part of our empirical analysis, the unit of observation is going to be a firm pair. In particular, using the firms in our sample we constructed 4465 pairings ($95 \times 94/2$). Across the various pairings we identified those having signed a cross license agreement and those having disclosed patent litigation. In particular three distinct patterns have emerged. In 22 cases firms litigated and terminated the litigation (either with a trial judgment or with a private settlement) without signing a cross license agreement. In 16 cases they terminated the litigation with a settlement involving a cross license agreement. Finally in 8 cases firms signed a cross license agreement without previous litigation.[10]

In the following table we present summary statistics for the variables related to capital intensities and patent portfolios across pairings. Totport indicates the sum of the two portfolios whereas Portratio indicates the ratio between the greater and the smaller in the pair. Similarly Avcapint indicates the average between the two capital intensity indexes of firms and Capintratio indicates the ratio maximum over minimum. Studying both variables across pairings and not at a single firm level reduces the skewness of the two distributions. In addition the table provides summary statistics for our four measures of 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 two product market measures. SIC is highly skewed to the left (median is zero) whereas BSVSIC is highly skewed to the right (median is 0.707).

	Mean	Std Dev	Median
Total Portfolio	788.92	1616.84	133
Portfolio Ratio	53.9	241.26	5.52
Average Capital Intensity	206.44	126.94	173.55
Capital Intensity Ratio	3.17	3.34	2.09
TECH	0.218	0.24	0.14
LINK	0.009	0.423	0
SIC	0.201	0.271	0
BSVSIC	0.577	0.407	0.707

Moreover, we calculated the correlation between the three measures. As we can observe in the following table the correlation between product market and technological distances is quite low. In particular it is lower than the one obtained in BSV(2004) but in line with the values obtained by Ornaghi (2005). As described in the previous section both SIC and BSVSIC are unsatisfactory measures of firms distance in the product market space. Their imperfection is straightforwardly observed from the very low correlation between them. In future research we intend to develop a better measure of product market similarity.

[10] There are 3 cases of litigation not concluded in 2004. There is no evidence from firm SEC filings of cross-license negotiation among these firms. As a robustness check, we run our regressions with and without these cases and results do not appear to be affected.

	TECH	LINK	SIC	BSVSIC
TECH	1			
LINK	0.26	1		
SIC	0.09	0.09	1	
BSVSIC	0.08	0.04	0.12	1

Let us say that there is a contact between two firms if there is evidence of litigation or cross license between them. In Table 1 we report summary statistics comparing firm pairings having a contact or not. Firm pairs involved in litigation or cross-licensing have a greater total portfolio and greater average capital intensity. In addition they are closer considering both technological distance measures and SIC distance. Performing a t-test we observe that both for portfolio ratio and for the capital intensity ratio means are not statistically different from each other at the 0.01 level.

The skewness of both average capital intensity and total portfolio can raise some doubts about the appropriateness of a t-test. As a robustness check we performed the same test on the logarithm of each observation obtaining the same levels of significance for the two variables. As additional robustness check we computed robust standard errors clustering for pairings involving the same company. Also in this case the significant levels of the t-test do not change.

In Table 2 we consider differences among firm pairings choosing different ways to deal with patent disputes. Table 2 reports summary statistics for firm pairs involved in litigation only, in litigation and cross license or in cross license only. Performing a one-way ANOVA test we observe that the only variables statistically different from each other at the 0.01 level are those related to the capital intensity.

Therefore, from the analysis of these summary statistics we 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 to be more correlated with firms' capital intensity than other variables.

6 Econometrics

In this Section we study firms choice between cross-licensing and litigating considering a firm pair as unit of observation. To this end we exploit the ordered variable OUTCOME that we defined above. 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, we 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, we 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

$$y^*_{2ij} = x'_{2ij}\beta_2 + u_{2ij}, \qquad \text{if a dispute is observed between } i \text{ and } j$$

where x_{2ij} and β_2 denote the vectors of explanatory variables and parameters and u_{2ij} is the error term.

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 8 describes this nested aspect that we have to consider in estimating the determinants of cross-licensing.

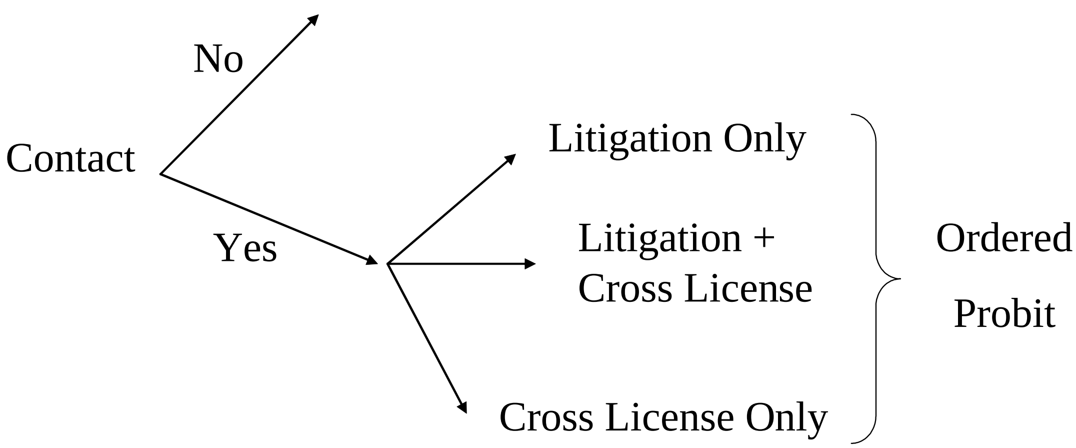

FIGURE 8: Nested Aspect of Disputes

For this reason, following Amemiya (1984), we 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

$$y^*_{1ij} = x'_{1ij}\beta_1 + u_{1ij} \qquad ij = 1, ..., n(n-1)/2 \tag{5}$$

and x_{1ij} and β_1 denote the vectors of explanatory variables and parameters and u_{1ij} is the error term. We 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:

$$E[y^*_{2ij}] = x'_{2ij}\beta_2 + E[u_{2ij}|CONTACT_{ij} > 0\ ] \quad (6)$$
$$= x'_{2ij}\beta_2 + E[u_{2ij}|\ u_{1ij} > -x'_{1ij}\beta_1]$$
$$= x'_{2ij}\beta_2 + \rho\frac{\phi(x'_{1ij}\beta_1)}{\Phi(x'_{1ij}\beta_1)} \quad (7)$$

where $\phi(.)$ is the standard normal density and $\Phi(.)$ its cumulative distribution function. It is therefore easy to see why the estimation of (6) may be biased whenever ρ is not zero.

To correct for this bias, and following Van De Ven and Van Praag (1981), we construct a likelihood function based on equations (5) and(6):

$$L = \prod_{CONTACT=0} P(\ y^*_1 \leq 0) \prod_{OUTCOME=1} P(\ y^*_2 < c_1\ \wedge\ y^*_1 > 0)$$
$$\prod_{OUTCOME=2} P(\ c_1 \ < \ y^*_2 < c_2 \wedge\ y^*_1 > 0) \prod_{OUTCOME=3} P(\ c_2 < y^*_2\ \wedge y^*_1 > 0).$$

In the Appendix we provide the precise formula that has been estimated given our assumptions on the distribution of $\{u_{1ij}, u_{2ij}\}$.

6.1 Discussion

Results of the regressions performed are reported in Tables 3 to 5. In particular, in Table 3 we provide various probit regressions in which we study which variables are determining the probability of observing either a patent dispute or a cross-license agreement between two firms. The main outcome from these regressions (and from others not reported) is captured in the first column of Table 3: 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 the portfolio of the two firms. In fact, total portfolio, TECH and LINK are the only variables that show up significant at the 0.01 level.

In the second column we present an interaction effect between TECH and total portfolio. This interaction does not show up significant (marginal effect computation follows Ai and Norton (2003)). Moreover, we tested other (non-reported) interactions as LINK-total portfolio and LINK-TECH but all of them show insignificant. In the third column we investigate the presence of nonlinear effects of total portfolio and also in this case we do not find any evidence for it. Similarly, we have not found any significant quadratic effect for TECH, LINK and average capital intensity. In the final three columns of Table 3 we examine if either our measures of product market distance or ratios between portfolios and capital intensities can explain observed contact. We do not find evidence supporting this claim. As an additional robustness check we run the probit considering logarithms both of total portfolios and of average capital intensity and this did not affect our results.

Analyzing the results of the probit regression in Table 3 it is interesting to note that the total portfolio effect is quite small with elasticity at the mean of 0.18. In particular, evaluating the portfolio marginal effect at the mean it is possible to observe that increasing the total portfolio of 100 patents we increase the probability of observing a dispute of only 0.0001. In addition it is possible to observe that both the portfolio elasticity and the portfolio marginal effects are increasing if we compute them at the 25th, the 50th and the 75th percentile of the total portfolios distribution (and we keep TECH and LINK at their mean).

We interpret this finding as an indication that, once TECH and LINK are kept constant, the probability of observing a dispute is proportional to the size of firms' portfolios. This can be consistent with a model in which each patent of firm i may infringe each of the patents of firm j with a constant probability α and infringements are identically and independently distributed across patents.

TECH distance marginal effect has elasticity at the mean of 0.83 and the LINK effect is the weakest with elasticity at the mean of 0.08. The fact that TECH elasticity is so large indicates that despite firms being quite homogeneously scattered across the technology space, disputes arise mostly among those that are technologically closer. This supports the views that most of the interactions observed in the Semiconductor industry arises because of patent substitutability and not because of patent complementarity. In the following section we discuss this issue in greater detail.

Exploiting these probit regressions we performed a Tobit II estimation correcting for the selection bias. The identification strategy (supported by our probit analysis) is to assume that LINK and TECH do influence the probability of observing a dispute but do not influence the choice of the dispute resolution technique and that capital intensity does not affect the probability of observing a dispute. Results of some of these regressions are reported in Table 4. In all the cases capital intensity is the only significant variable.

Performing the same regressions without correction it is possible to observe that the coefficient for the patent portfolio is overestimated and the coefficient for average capital intensity is underestimated but nevertheless it remains the only significant variable in most of the regressions. Interestingly, comparing the regressions with and without correction it is possible to notice that for the average capital intensity coefficients the confidence intervals overlap. This is due to the fact that the correlation between the error terms is never statistically significant and therefore that the expectation in the final term of equation (6) is zero.

In Table 5 we tested the predictions obtained from the two-period game. In columns 1-2 we analyzed the effect of product market relatedness and its interaction with capital intensity. According to the result described in lemma 2 we should expect a negative coefficient on the product market distance. In addition we should expect a positive coefficient for the interaction because the competition effect is smaller for capital intensive firm pairings. From our regressions we do not observe this pattern. The coefficients both on distances and on interactions are never significant and always of the wrong sign.

More satisfactory are the results on capital intensity asymmetries. In lemma 3 we observed that it is an increase in the capital intensity of the firm with lower bargaining power that has greater impact on the choice of the dispute resolution technique. In our framework we believe it is reasonable to consider the firm with smaller portfolio as the firm with lower bargaining power.

The basic idea is that firms with larger portfolio have a higher probability to hold-up the counterpart rather then being held-up. This interpretation is consistent with previous literature suggesting that large portfolio can be used as bargaining "chips" in dispute settlements (Hall and Ziedonis (2001) and Lanjouw and Schankerman (2004)).

In column 3 we considered this asymmetry exploiting a weighted average of capital intensity with weights inversely related to the relative portfolio size. More precisely we adopted the following weighted average for firms' capital intensity:

$$\text{Weightedcapint}_{ij} = \text{capint}_i * \frac{\log\left(\text{portfolio}_j\right)}{\log(\text{portfolio}_i * \text{portfolio}_j)} + \text{capint}_j * \frac{\log\left(\text{portfolio}_i\right)}{\log(\text{portfolio}_i * \text{portfolio}_j)}.$$

Also in this case the coefficient is positive and significant at the 0.01 level.

As robustness check, we adopted two alternative measures for capital asymmetry. First, we considered only the capital intensity of the firm with the lowest portfolio. In column 4 it is possible to observe that the coefficient is positive and significant at 5%. Second, we considered the weighted sum of capital intensity considering plant and equipment net of depreciation and still the coefficient is significant at the 0.01 level. These results confirm the prediction of lemma 3 and imply that the capital intensity of the firm with lower bargaining power plays an important role in determining the choice of the dispute resolution technique.

As additional robustness check we constructed a dummy for firm pairings that are members of the SEMATECH[11] R&D consortium (for a detailed analysis of this consortium see Spencer and Grindley (1993)). This dummy does not seem to be significantly affecting the choice between the different dispute resolution techniques.

6.2 Cross-License vs Litigation: Complementarity Reasons?

From the previous analysis we can conclude that capital intensity, because it renders litigation more costly, has a strong impact on firms' choice of whether to litigate or

[11] SEMATECH is a consortium formed in 1987 by 12 private U.S. companies together with the U.S. Department of Defence. Only 4 firms of our sample have been members of SEMATECH for the period under study. We observe only one cross-license agreement between two of these firms and this agreement has been signed after three years of litigation.

to cross-license. In this Section we want to explore the possibility of another reason behind cross-license agreements: technological complementarities.

Previous literature, in particular Grindley and Teece (1997), pointed out that cross-licensing in industries characterized by cumulative innovation (as semiconductors) is aimed at ensuring "freedom to manufacture" whereas in other industries where innovation is less cumulative (as chemicals) cross-licensing is more likely to be aimed at exchanging technology.

Can we rule out technological exchange motives from the cross-licensing that we observe in the Semiconductor Industry? To answer to this question, we try to capture technological complementarities exploiting our LINK measure in various empirical exercises.

First, we modified the previous ordered probit setting, adopting an alternative identification strategy. We assumed that only TECH and the total portfolio were the variables influencing the probability of observing a CONTACT. In this framework it is possible to compare the significance of the capital intensity coefficient with the significance of the LINK coefficient. In all the regression estimated capital intensity is always significant at the 0.01 level whereas LINK is never significant.

As a robustness check we introduced LINK in both in the OUTCOME and in the CONTACT equation and we observed that it keeps being insignificant in the first and significant in the second. This negative result can indicate either that LINK is completely unrelated to the dispute resolution mechanism or that it is related only to the choice between cross-licensing or not and does not affect the decision of litigation before a cross-license.

To check whether LINK influences cross-licensing or not we performed a t-test and observed that firm parings signing a cross-license (conditional on disclosing a dispute) not only have larger capital intensity but also larger LINK measure (we did not find any difference for the TECH measure).

In addition we performed a two-stage probit regression, estimating the probability of cross-license as function of LINK and average capital intensity. In this regression the LINK coefficient is positive and significant at the 0.05 level whereas the one for average capital intensity is significant at the 0.01 level.

From the results of these exercises, we cannot reject technological complementarity reasons for cross-license in the Semiconductor Industry. In fact, the LINK coefficient does appear moderately significant in the two-stage probit regression and this can be an indication of technology exchange between firms. Nevertheless it is important to notice that the coefficient on average capital intensity remains very significant and therefore, if technological exchange reasons are present in this Industry, they do not replace the "freedom to manufacture" motives discussed in our model.

6.3 Robustness Check: Firm Level Analysis

To test the robustness of our result we adopt an alternative econometric strategy: we conduct the analysis considering the single firm as a unit of observation. Our main concern in this Section will be the estimation of the following equation:

$$y_i = \beta' x_i + \varepsilon_i \tag{8}$$

where the dependent variable y_i is going to be the percentage of observed disputes resulting either in immediate cross-license agreements or the percentage of observed disputes resulting in litigations without cross-license. In addition β is going to be a vector of unknown parameters and x_i a vector of the exogenous variables for observation i: portfolio, capital intensity, average LINK, average TECH, average product market distance and a constant term. Finally we assume $\varepsilon_i \sim N(0, \sigma)$.

Estimation of (8) is complicated because of a selection problem in our data. In fact, a relevant fraction of the firms in our sample (48/95) are not involved in any observable dispute. We inspected the characteristics of these firms and we found that they have a smaller patent portfolio, and lower average TECH and LINK distances. In fact performing both a mean comparison t-test and a median comparison test we found a statistical difference at the 0.01 level. This differences lead us to analyze this selection problem by means of a probit regression. More precisely we defined the variable CONTACT as a dummy getting value of one if the firm has disclosed some form of dispute over its intellectual property and value of zero otherwise. We assume that CONTACT is affected by a latent variable z^* in the following way:

$$CONTACT_i = \begin{cases} 1 & \text{if} \quad z_i^* > 0 \\ 0 & \text{if} \quad z_i^* \leq 0 \end{cases} \tag{9}$$

where

$$z_i^* = \gamma' v_i + u_i$$

with v_i a vector of exogenous variables and $u_i \sim N(0, 1)$.

Performing this probit regression we observed that only average LINK and average TECH where statistically significant in all the regressions. A firm with an average LINK of 0.009 (the mean of the LINK distribution) discloses at least a dispute with probability 0.63. Evaluated and this point the elasticity respect to average LINK is 0.67. It is interesting to note the difference between this probit regression and the similar analysis that we carried out at the firm pair level. In fact, in that setting, also total portfolio was significant in predicting the probability of observing some interaction. A possible explanation for the irrelevance of portfolio is the fact that only firm with large portfolios seem to have large values for the average LINK measure. In particular the correlation between average LINK and portfolios is quite high (0.81) and, in a linear regression model the estimated correlation between the coefficients of the two variables is -0.78. Therefore we suspect that this absence of portfolio effect is due to multicollinearity.

Results of this probit estimation are exploited to correct (8) for its selection bias. Following Amemiya (1984) we link equation (8) and (9) by assuming a correlation between ε_i and u_i equal to ρ and maximizing the following Tobit II likelihood function:

$$L = \prod_{y=0} \text{Prob}(\ z_i^* \leq 0) \prod_{y=1} f(\ y_i\ /\ z_i^* > 0) \text{Prob}(\ z_i^* > 0)$$

where f is the density function of y. In our setting this function can be rewritten as (see Amemiya (1984) for a derivation):

$$L = \prod_{y=0} \Phi(-\gamma' v_i) \prod_{y=1} \frac{\Phi\left(\dfrac{\gamma' v_i + (y_i - \beta' x_i)\rho/\sigma}{\sqrt{1-\rho^2}}\right)}{\phi((y_i - \beta' x_i)/\sigma)} \tag{10}$$

where $\Phi()$ is the standard cumulative normal and $\phi()$ is the standard normal density.

Results of some of the regressions performed are reported in Table 6. More specifically, in Table 6 we regress the percentage of total observed disputes that resulted in immediate cross-license agreements on firm capital intensity and other covariates. In the first two columns of Table 6 we perform simple OLS regressions and, as we can observe, capital intensity appears the only variable statistically significant at the 0.01 level. In the last three columns of Table 6 we correct for the selection bias present in our data. Exploiting the results of the Probit regression (9) we estimate the regression coefficients maximizing the likelihood function (10).

The results obtained show that with standard OLS techniques the capital intensity parameter (despite being statistically significant) results underestimated by 40 percent. In a Tobit II framework it is possible to notice that an increase in firm plant and equipment of \$1,000 per employee moves 0.1% of the disputes toward cross-licensing without litigation. Exploiting our regressions we can predict that a firm involved in three disputes is likely to sign at least one immediate cross license agreement if its capital intensity lies on the 75th percentile of the capital intensity distribution (\$120,000 net of depreciation or \$250,000 gross) whereas we would expect two agreements if the percentile is the 95th (\$325,000 net and \$550,000 gross).

In addition we have also computed a similar regression in which the dependent variable is the percentage of observed disputes that resulted in litigation without cross-license. As in the previous analysis, capital intensity is statistically significant both in a simple OLS framework and in a corrected Tobit II model. Nevertheless, in this regression not only its marginal effect is magnified after the correction but also the statistical significance is improved.

Combining the results obtained in the previous regressions, we expect the firm with median capital intensity in our sample not to sign a cross license for 78% of its dispute and to sign an immediate cross license agreement for 15% of them (and to delay the agreement for the remaining 7%). Conversely for a firm with capital intensity at the 95% percentile we expect it to sign immediate cross-license agreements for 55% of its dispute and to litigate without cross-license for 43% of the cases (and delaying only 2% of the cases).

Various robustness checks have been carried out to support the results obtained. In particular, we run again all the regressions not performing a maximum likelihood estimation but exploiting the two-step Heckman correction model (see Heckman (1979) and Willis and Rosen (1979) for details). Capital intensity remains significant and the magnitude of its marginal effect does not vary. Moreover, we corrected for the selection bias using a first stage Probit regression on the average Tech measure and not on the average link. Also in this case average capital intensity remains the only significant variable.

It is important to notice that in all our regressions X, the set of covariates that affects the outcome, and V, the set of covariates that determine selection, do not overlap. In principle the model is identified even when the variables in X and V are the same but in this case identification depends exclusively on the nonlinearity of our model and on the normality assumption being satisfied. Despite this being a strong assumption, as a robustness check we estimate (10) adopting only average LINK and average TECH as variables in X and V. Also in this case, these variables appear significant at 0.01 in the selection equation but insignificant in the outcome equation.

7 Conclusion

In this paper we study cross-license agreements in the Semiconductor Industry. We develop a model of bargaining with learning in which the firms' decision to litigate or to sign a cross license agreement depends on their capital intensity. In particular the model predicts that high capital intensity reduces the likelihood of litigation and increases the likelihood of cross-licensing. Using a novel dataset on the Semiconductor Industry we obtain empirical results generally consistent with those suggested by the model.

In future research we plan to improve our work studying more in detail complementarity and substitutability of cross-licensed portfolios. These results will be helpful for an anti-trust assessment of these agreements.

Finally the results obtained can shed some light on the debate about patent system reform. Various economists have recently questioned the optimality of the current patent system (e.g. Gallini and Scotchmer (2002) and Shapiro (2001)) and even proposed the elimination of it (e.g. Quah (2006), Boldrin and Levine (2002) and Bessen and Maskin (2000)). In this paper we pointed out some circumstances in which the market endogenously renounces to Intellectual Property. Therefore our analysis can help to understand in which circumstances costs associated with patent rights seem to outweigh benefits provided by the system.

8 Appendix

8.1 Proof of Proposition 1

It is easy to see that only if $V - 2F(1-k) \geq \overline{u} + \underline{u}$ there will be agreement. Indeed, for k low enough this inequality is not satisfied and therefore only if k is large enough there will be agreement. In particular we have equality at $1 - \frac{2L}{F} = \underline{k}$.

Define $V_t^i(m)$ 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.

We define the agreement regime the case in which

$$\frac{V - 2F(1-k)}{1-\delta} \geq \overline{u} + \underline{u} + \delta S_{t+1}. \tag{11}$$

In this case the player chosen by the nature extracts the rent $\frac{V - 2F(1-k)}{1-\delta} - \overline{u} - \underline{u} - \delta S_{t+1}$. We define the no agreement regime the case in which (11) is not satisfied. In this case the rent extracted is zero. We can therefore define the rent extracted in period t as:

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

Moreover

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

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

This can be re-written as

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

and it implies that

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

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

From the previous definitions we observe that in the agreement case:

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

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

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

Notice now that a condition to have agreement is

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

We can rewrite this condition as

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

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

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

This condition can be rewritten as

$$y_t - y_{t+1} \leq \frac{1-\delta}{\delta} - \frac{(\overline{u} - \underline{u})(1-\delta)(1+\delta y_{t+1})}{(V - 2F(1-k) - 2\underline{u})\delta} \tag{12}$$

$$y_t - y_{t+1} \leq \frac{1-\delta}{\delta} - A(k)\frac{(1-\delta)(1+\delta y_{t+1})}{\delta} \tag{13}$$

The formula

$$A(k) = \frac{\frac{V}{2} - F(1-k)}{2L - 2F(1-k) + \frac{V}{2}}$$

is what differentiate our model from the one of Yildiz(2003) in which the outside options $\overline{u}$ and $\underline{u}$ are not present. It is easy to see that $A(k)$ is a decreasing function[12] and therefore that with an increase in capital intensity (higher k) the right hand side of (12) 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.

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

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:

$$\frac{\Delta}{n(n+1)} \leq \frac{1-\delta}{\delta} - \frac{(\overline{u}-\underline{u})(1-\delta)(1+\frac{\delta\Delta}{n+1})}{(V-2F(1-k)-2\underline{u})\delta}. \tag{14}$$

Notice that k^* is defined as the value of k for which (14) holds with equality. We can re-write (14) as

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

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

Notice that $A(\underline{k}) = 1$ and $A(1) = \dfrac{V/2}{V/2+2L} > 1/2$. It is easy to see that $f'(k) < 0$.

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

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

In this range we have that $\lim_{\delta\to 0} g(k,\delta) = +\infty$ and $\lim_{\delta\to\overline{\delta}} g(k,\delta) = 0$.

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 $1 = A(k)$).

Finally because of the implicit function theorem we have that

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

The following figure summarizes our results.

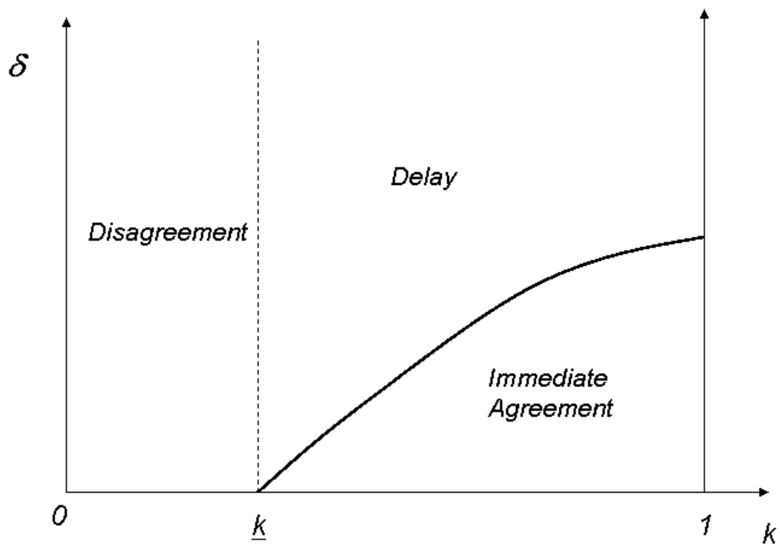

Figure 8: Markov-Perfect Nash Equilibrium

8.2 Derivation of the Ordered Probit Likelihood Function

Following Van De Ven and Van Praag (1981) and we are 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 we obtain the formula for the likelihood function:

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

8.3 Technological Categories

These are the 23 product market categories we identified.

1. Diodes
2. Small Signal Transistors
3. Power Transistors
4. Rectifiers
5. Thyristors
6. Optoelectronics

7. Sensors and Actuators
8. Standard Linear
9. Application Specific Analog
10. MOS MPU
11. MOS MCU
12. MOS Digital
13. Logic Standard
14. Special Purpose Logic
15. MOS DRAM
16. MOS SRAM
17. MOS Mask Program ROM
18. MOS EPROM
19. NOR Flash EEPROM
20. NAND Flash EEPROM
21. Other Memory
22. Test and Assembly
23. Solar Sistem

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TABLE 1: Comparison of firm pairings with and without contact

Variable	No Contact	Contact	p value
Total Portfolio**	**766.63**	**2930.39**	0.000
	(23.71)	**(480.75)**	
Portratio	54.01	42.68	0.751
	(3.64)	(14.33)	
Avcapint**	**205.91**	**257.78**	0.005
	(1.90)	**(19.85)**	
Capintratio*	3.18	2.11	0.030
	(0.05)	(0.17)	
TECH**	**0.21**	**0.54**	0.000
	(0.003)	**(0.03)**	
LINK**	**0.008**	**0.115**	0.000
	(0.0005)	**(0.02)**	
SIC**	**0.20**	**0.32**	0.002
	(0.004)	**(0.03)**	
BSVSIC	0.57	0.60	0.629
	(0.006)	(0.056)	

**t-test signifincant at 1% *t-test signifincant at 5%

TABLE 2: Comparisons of different dispute resolution techniques

Variable	Litigation Only	Litigation & CL	CL only	Prob (F-Test)
Total Portfolio*	1652	3738	4829	0.025
	(2811)	(3390)	(3039)	
Portratio	26.10	61.28	51.07	0.536
	(54.62)	(146.34)	(64.43)	
Avcapint**	**197.23**	**265.83**	**408.16**	0.000
	(101.91)	**(103.57)**	**(157.86)**	
Capintratio**	1.88	1.83	3.28	0.004
	(0.81)	(0.81)	(1.79)	
TECH	0.57	0.48	0.59	0.444
	(0.26)	(0.25)	(0.19)	
LINK	0.07	0.15	0.15	0.211
	(0.10)	(0.19)	(0.19)	
SIC	0.20	0.29	0.34	0.727
	(0.27)	(0.21)	(0.26)	
BSVSIC	0.47	0.70	0.76	0.083
	(0.45)	(0.28)	(0.24)	

**ANOVA-test signifincant at 1% *ANOVA-test signifincant at 5%

TABLE 3: Probit on Contact

Contact	(1)	(2)	(3)	(4)	(5)	(6)
Totport(x1000)	**0.08 (0.02)****	**0.13 (0.04)****	0.06 (0.06)	**0.08 (0.02)****	**0.09 (0.02)****	**0.09 (0.03)****
Portratio(x1000)						-0.03 (0.59)
Avcapint(x1000)				-0.26 (0.64)	-0.25 (0.64)	-0.07 (0.60)
Capintratio						-0.07 (0.04)
TECH	**1.29 (0.19)****	**1.48 (0.22)****	**1.29 (0.19)****	**1.28 (0.20)****	**1.34 (0.19)****	**1.14 (0.20)****
LINK	**3.09 (0.66)****	**3.03 (0.63)****	**3.11 (0.67)****	**2.97 (0.66)****	**3.04 (0.66)****	**3.00 (0.64)****
TECH*Totport(x1000)		-0.10 (0.07)				
$Totport^2$(x1000)			-0.02(0.06)			
SIC				0.27 (0.19)		0.23 (0.18)
BSVSIC					-0.15 (0.14)	
Constant	-3.00 (0.13)**	-3.09 (0.15)**	-2.99 (0.12)**	-3.01(0.13)**	-2.88 (0.14)**	-2.79 (0.16)**
Number of obs	4465	4465	4465	4465	4465	4465
Log Pseudolikelihood	-198.30	-197.63	-198.26	-197.51	-197.74	-195.19
Pseudo R2	0.226	0.228	0.226	0.229	0.228	0.238

**significant at 1%   *significant at 5%

Robust Standard Error Adjusted for Name Clusters Reported in Parenthesis.

TABLE 4: Ordered Probit on OUTCOME

	(1)	(2)	(3)	(4)
Average Capital Intensity*1000	**5.29**	**5.26**	**5.53**	**5.45**
	(1.79)**	**(1.73)****	**(1.66)****	**(1.93)****
Total Portfolio*1000		0.02		
		(0.08)		
SIC			0.46	
			(0.87)	
BSVSIC				0.84
				(0.47)
Constant1	0.40	0.41	0.72	1.13
Constant2	1.64	1.65	1.99	2.44
Ro	-0.40	-0.39	-0.34	-0.32
First-Stage				
Total Portfolio*1000	0.08	0.08	0.08	0.08
	(0.01)**	(0.02)**	(0.02)**	(0.02)**
TECH	1.26	1.26	1.27	1.26
	(0.17)**	(0.18)**	(0.17)**	(0.18)**
LINK	3.15	3.15	3.14	3.17
	(0.61)**	(0.61)**	(0.61)**	(0.61)**
Number of obs	4465	4465	4465	4465
Log pseudolikelihood	-236.24	-236.24	-236.06	-234.80

Tobit II maximum Likelihood

* significant at 5% level ** significant at 1% level

Robust Standard Error Adjusted for Name Clusters Reported in Parenthesis.

TABLE 5: Ordered Probit on OUTCOME

	(1)	(2)	(3)	(4)
Average Capital Intensity*1000	**6.31** **(2.81)***	3.87 (2.11)		
Weighted Capital Intensity			**5.22** **(2.04)****	
Minimum Portfolio Capital Intensity				**1.81** **(0.82)***
Total Portfolio*1000			0.04 (0.08)	0.09 -0.07
SIC	1.06 (1.71)		1.27 (0.99)	0.06 -0.84
BSVSIC		0.12 (0.93)		
SIC*Average Capital Intensity	-0.002 (0.004)			
BSVSIC*Average Capital Intensity		0.002 (0.003)		
Constant1	0.95	0.75	1.34	0.05
Constant2	2.23	2.09	2.68*	1.22
Ro	-0.34	-0.30	-0.21	-0.25
First-Stage				
Total Portfolio*1000	0.08 (0.02)**	0.07 (0.02)**	0.08 (0.02)**	0.08 (0.02)**
TECH	1.27 (0.17)**	1.26 (0.18)**	1.28 (0.18)**	1.27 (0.18)**
LINK	3.13 (0.61)**	3.18 (0.61)**	3.11 (0.64)**	3.14 (0.62)**
Number of obs	4465	4465	4465	4465
Log pseudolikelihood	-235.99	-234.61	-235.59	-239.25

Tobit II maximum Likelihood
significant at 5% level ** significant at 1% level
Robust Standard Error Adjusted for Name Clusters
Reported in Parenthesis.

TABLE 6: Dependent variable: immediate cross-licenses/ total disputes (in percentage)

	(1)	(2)	(3)	(4)	(5)
Capital Intensity	**0.07**	**0.07**	**0.09**	**0.10**	**0.10**
	(0.01)**	**(0.01)****	**(0.01)****	**(0.01)****	**(0.02)****
Patent Portfolio*1000		0.56		-2.93	-2.73
		(2.65)		(3.35)	(3.37)
Average TECH		14.94		41.42	-46.99
		(26.04)		(53.48)	(44.13)
Average SIC		6.56		-11.48	
		(25.17)		(47.82)	
Average BSVSIC					-16.63
					(49.19)
Constant	-7.17	-11.08	-3.45	-12.08	-7.69
	(3.39)*	(6.33)	(8.94)	(22.40)	(35.85)
First-Stage					
Average LINK			104.05	104.05	104.05
			(30.82)**	(30.82)**	(30.82)**
Avearge TECH			2.31	2.31	2.31
			(0.08)**	(0.08)**	(0.08)**
constant			-1.19	-1.19	-1.19
			(0.02)**	(0.02)**	(0.02)**
corr			-0.05		
Number of obs	95	95	95	95	95
R-squared	0.28	0.29			
Wald chi2			22.52	26.84	27.16

(1)-(2) OLS (3)-(5) Tobit II Maximum Likelihood

* significant at 5% level ** significant at 1% level '(1)-(5) Robust Standard Error Reported in parenthesis.