Sloan School of Management
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15.013 – Industrial Economics for Strategic Decisions
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Lecture Notes
on
R&D and Patent Licensing

(Revised: July 2017)

These notes cover some of the material that we will discuss in class on R&D, patenting, and patent licensing. Our overall concern is with the value of patents as a tool for strategic competition, and also as options that might sometime be exercised to create commercial products. We will examine licensing as a way to reduce industry output and increase prices, but also as a way to do just the opposite — to commit to *lower* prices in the future. We will see how the incentives to license can be particularly strong when there are network externalities, and we will examine alternative ways of licensing a patent. Finally, we will see how patent pools can help solve the problems that arise when a company develops a product (such as a smartphone) that involve hundreds of patents that are owned by different companies. To begin, we will see that patents sometimes offer only limited protection for intellectual property.

1 Do Patents Protect Innovations?

One reason — perhaps the most important — that firms patent their innovations is to protect those innovations from unwarranted use (perhaps theft is a better word) by other firms. If a firm can prove (in court) that another firm has infringed on one or more of its patents, it can seek damages from that other firm, and also prevent the other firm from continuing to produce any products that use the infringed patents.

Patents, however, do not always completely protect a firm's innovations. The many patents that go into Apple's iPhone are a good example of this. (See Figure 1.) The

DO PATENTS PROTECT INNOVATIONS?
Apple's iPhone Patents

Figure 1: Apple's iPhone

extent of the protection that the patent can provide depends on the nature of the patented innovation. For some innovations the patent provides excellent protection; for others it does not. Two patents in particular illustrate this.

Figure 2 shows a schematic drawing of the fuel cell system that powers the iPhone. This system is critical to the operation of the iPhone, because it enables the phone to stay charged for long periods of time. Naturally, the system was patented (Patent # US20110311895). It turns out that this particular patent provides Apple with excellent protection. No other companies have tried to copy the innovation or otherwise infringe on the patent.

Figure 3 shows a quite different piece of technology that is also an important part of the iPhone. Using the phone's touch screen, this innovation allows a user to interact with text in a variety of ways, including "copy and paste" functions, or finding the definition of a word. Although this technology has also been patented, other companies (and in particular Samsung) have developed and used content display systems that — at least in Apple's view — that are very close to the Apple system. Indeed, Apple and Samsung have both claimed that the other firm has infringed on its content display patents. These claims have led to ongoing litigation.

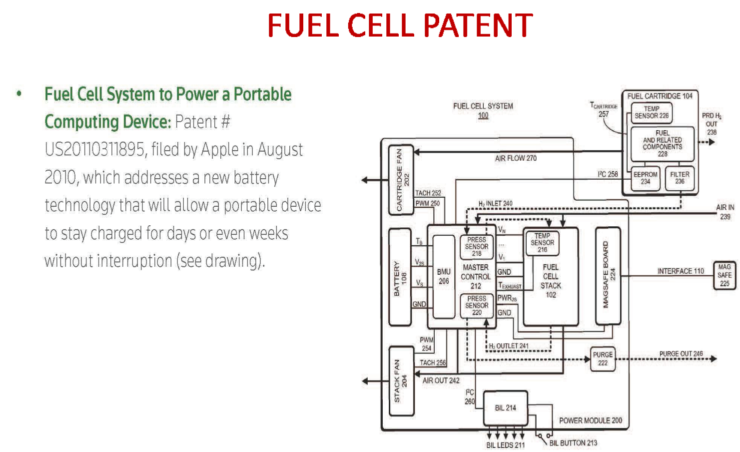

Figure 2: Patent for iPhone's Fuel Cell System

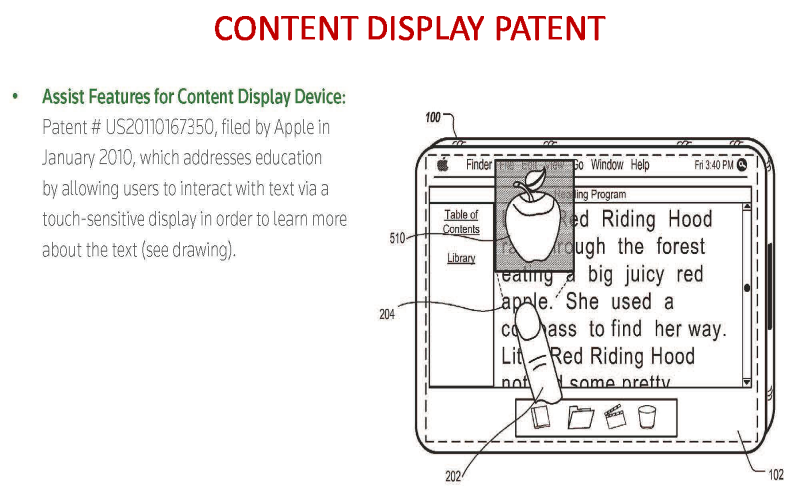

Figure 3: Patent for iPhone's Content Display

Why is it that Apple's fuel cell patent has provided strong protection, whereas its content display patent has been (allegedly) infringed, and has been hard to defend? Figure 4 compares the two patents. The key difference is that the battery technology in the fuel cell system is extremely clear-cut. Every component and electrical connection in the system is clearly in the diagram, which makes it relatively easy to demonstrate infringement, should it occur. The content display patent, on the other hand, is algorithm based, and almost any algorithm can be easily modified so that it still does the same job, but works a bit differently.

Patents that based on algorithms are difficult to defend because algorithms are easily

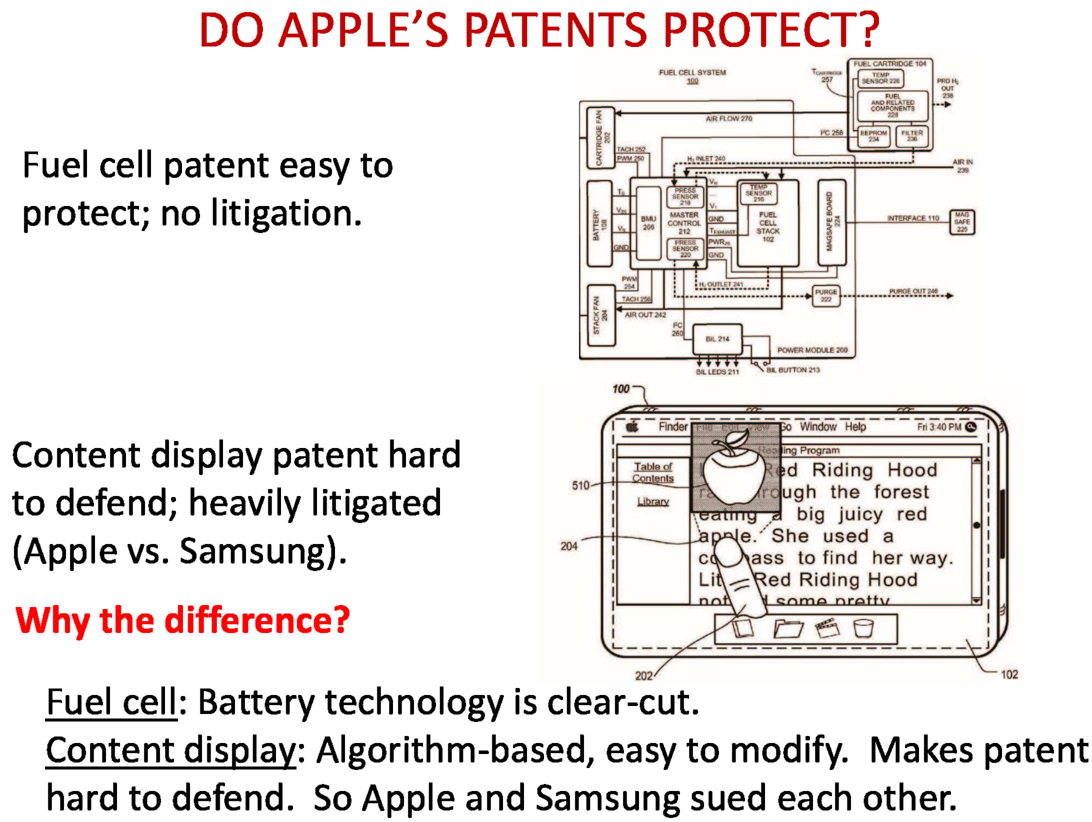

Figure 4: Fuel Cell Patent vs. Content Display Patent

modified, and as a result, such patents provide a firm with only limited protection of its intellectual property. This is also true of process-based patents, e.g., a patented process to manufacture a biotech drug based on recombinant DNA technology.

The fact that algorithm-based patents are difficult to defend raises an interesting question: Why bother patenting these innovations? Remember that there is a downside to patenting an innovation: doing so is costly, and it reveals a good deal of information about the nature of the innovation. So why did Apple patent its content display system? We will discuss this in class.

2 Patenting to Deter Entry

We begin by examining how R&D can be used strategically to deter entry. First, we will see how an incumbent monopolist might develop and patent a variety of substitute technologies.

Although most will never be commercialized, they can help deter entry by potential competitors. Second, we will see why a large technology firm (e.g., Apple or Google) might buy portfolios containing thousands of patents, thereby creating "patent thickets" that likewise can deter entry.

2.1 Preemptive Patenting

We have seen how capacity expansion and brand proliferation can be used as entry deterrents. Now we will see how a monopoly can preemptively patent as a way to deter entry. The basic idea is that a firm with monopoly power may have an incentive to patent new technologies before potential competitors do, but then never bring those patents to the market—i.e., hold "sleeping patents."[1]

Suppose an established firm has a monopoly position in the sale of some product (e.g., a drug to treat migraine headaches). Entry can take place only through the invention and patenting of a substitute for that product (e.g., a comparable drug). For simplicity, assume that the cost of inventing the substitute depends only on the *expected time lag* T, i.e., $C(T)$, with $C'(T) < 0$. In other words, the faster you try to develop the substitute product, the more it will cost to do so.

Should the monopolist spend money on substitute products in order to preempt potential competitors? The answer will depend on the profit streams that occur with and without entry. We will see that the monopolist will spend more on R&D than rivals will, *if entry results in a reduction of total profits below the joint maximizing level*. This can be seen through the following simple model.

Good #1 is the good originally produced by the monopolist. Let Good #2 be the substitute product, which might be produced by the entrant, or by the monopolist if the monopolist develops it *and* brings it to market. We will assume that there is free entry into the patent race, and that there are plenty of other firms that could potentially develop a substitute product. Therefore, entry will occur up to the point that for competitive entrants,

[1] This is essentially a summary of the main points in Gilbert and Newbery, "Preemptive Patenting and the Persistence of Monopoly," *American Economic Review*, June 1982.

the cost of R&D will just equal the resulting gains:

$$C(T) = \int_T^{\infty} \pi_e(P_m^1, P_e^2) e^{-rt} dt \tag{1}$$

where $\pi_e(P_m^1, P_e^2)$ is the profit to the entrant when it is in the market selling Good #2 at the price P_e^2 and the monopolist sells Good #1 at price P_m^1. The interest rate r might be adjusted appropriately for risk.

Suppose that entry indeed occurs at the competitive entry date T. Then total profits to the (former) monopolist are:

$$V_e = \int_0^T \pi_m(P_m^1) e^{-rt} dt + \int_T^{\infty} \pi_m(P_m^1, P_e^2) e^{-rt} dt \tag{2}$$

From the first equation, the monopolist *knows* what the competitive entry date will be, so it can preempt by bringing out the patent just ahead of time. The monopolist can then calculate the difference between profits with preemption and profits with entry:

$$V_p - V_e = \int_T^{\infty} \pi_m(P_m^1, P_m^2) e^{-rt} dt - \int_T^{\infty} \pi_m(P_m^1, P_e^2) e^{-rt} dt - C(T) \tag{3}$$

Note that the monopolist's price of Good #1, P_m^1, can be different depending on whether or not there is entry. Here P_m^2 is the price the monopolist charges for Good #2, but note that *the monopolist might not even produce the patented substitute good*, and instead simply let the patent "sleep."

Is preemptive patenting by the monopolist worthwhile? To find out, substitute the first equation (1) for $C(T)$ into equation (3) to get an alternative expression for the relative benefits of preemptive patenting:

$$V_p - V_e = \int_T^{\infty} \{\pi_m(P_m^1, P_m^2) - [\pi_m(P_m^1, P_e^2) + \pi_e(P_m^1, P_e^2)]\} e^{-rt} dt \tag{4}$$

We want to know whether the monopolist's profits from preemptive patenting will exceed the profits it earns if it instead allows entry. It will if:

$$\pi_m(P_m^1, P_m^2) > \pi_m(P_m^1, P_e^2) + \pi_e(P_m^1, P_e^2) \tag{5}$$

Note that the left-hand side of this inequality is the maximum profit that the monopolist earns when there is no entry, and the right-hand side is the total industry profit (the profit to the monopolist *plus* the profit to the entrant) when there is entry. Hence, *whenever entry reduces total profits, it will be better for the monopolist to preempt.*

Should we, as a general matter, expect that entry would reduce total profits? We probably would, unless we think that there would be some kind of collusion occurring after entry. Also, note that we do not require that the *monopolist's* profits be the same after entry, only that *total profits* do not fall.

The basic idea here is fairly simple. *The monopolist has a lot to gain*, i.e., a lot to protect, and is therefore likely to preempt in order to remain a monopolist. The entrant, on the other hand, has much less to gain by doing the necessary R&D to come up with a substitute product, because he will face a competitor upon entering.

Question: Suppose that in a particular market a monopolist finds it optimal to deter entry by patenting early. If a potential competitor knows that this is a rational strategy for the monopolist, that competitor will not enter, i.e., will not undertake the R&D. *But since the monopolist knows this, does the monopolist actually need to carry out the R&D plan?* Isn't the threat sufficiently credible so that no R&D need be done, and no sleeping patents need be accumulated?

The answer to this question depends on whether the monopolist can accelerate its R&D activity in response to R&D by a competitor, and whether the competitor's R&D activities can be observed. If the monopolist can see or infer what the competitor is doing, and can accelerate its own R&D activities, then the threat would indeed be credible, and the actual R&D and development of sleeping patents would not be necessary. However, delays are usually costly, and R&D activities are often not revealed, so that the preemptive patenting would probably have to be done.

Suppose the monopolist goes ahead and develops a substitute product and patents it. Should the monopolist let the patent sleep or should it commercialize the new technology? The answer depends on the size of the development costs, i.e., the costs required to commercialize the technology. If these costs are large, the monopolist would probably let the patent sleep. In particular, it would be better to let the patent sleep if, after subtracting the amortized development costs from profits, we find that:

$$\pi_m(P_m^1, P_m^2) < \pi_m(P_m^1) \tag{6}$$

Note that this reveals another welfare loss from monopoly power—not only is the price higher and output lower than would be the case in a competitive market, but in addition *resources are spent on new technologies that will never benefit consumers*.

Keep in mind that preemptive patenting does not always work. Potential competitors may be able to get around patents by making minor design changes. The costs of an infringement lawsuit may be large relative to the gains from patent enforcement. Also, firms are often dependent on each other for the use of patented technologies, and this encourages cross-licensing of patents and discourages restrictive patent enforcement. Finally, the gains from entry prevention may be small or ephemeral if the firm does not continue to introduce improved technologies and develop new products to capture a substantial market.

2.2 Patent Thickets

In 2011, a consortium of Apple, Microsoft, and other large firms bought a portfolio of about 6,000 patents from Nextel for $4.5 billion (outbidding Google).[2] Google then acquired Motorola Mobile for $12.5 billion, which gave Google a portfolio of over 17,000 patents. In 2012, Microsoft bought nearly 1,000 patents from AOL for about $1 billion, and then sold some of the patents to Facebook for $550 million. Why would these firms pay so much for large portfolios of patents, most of which have no obvious current or future application?

As discussed below, patents can have option value, even if at the moment it is unclear if or how they might ultimately be used. But it is hard to justify the kinds of sums that companies have been paying for patent portfolios simply on the basis of option value. The value of these portfolios is easier to understand if we note that in the examples given in the preceding paragraph, the firms involved are producers of computers (broadly defined), smartphones, semiconductors, and software. In these industries, a product might require

[2] This section draws on A. Hagiu andd D. Yoffie, "The New Patent Intermediaries: Platforms, Defensive Aggregators, and Super-Aggregators," *Journal of Economic Perspectives*, Winter 2013.

hundreds of patents, and often it is difficult to know whether a firm's technology might infringe other firms' patents. Apple, for example, has over 1,300 patents embodied in its iPhone technology, and it would be difficult for a competitor such as Samsung or Motorola to know in advance whether its own smartphones might infringe on Apple's patents. Thus technology firms face a constant risk of litigation, the outcome of which can be extremely expensive. An example is the recent litigation between Apple and Samsung; in September 2012, Apple won a patent infringement suit against Samsung and was awarded $1 billion in damages. (Samsung has counter-sued, claiming that Apple has infringed on some of its patents.) In fact, between 2008 and mid-2012, Apple has been the defendant in 263 patent lawsuits, the counter-claimant in 120 lawsuits, and the plaintiff in 51 lawsuits.[3]

These large patent portfolios create a *patent thicket*; a set of patents so vast that it becomes nearly impossible for competitors to avoid infringement, or even know if they are infringing. Given the growing threat of litigation, a patent thicket can be a powerful weapon and competitive tool:

- Any potential or actual competitor faces the cost of litigation risk. Holding a large portfolio of patents can greatly raise that risk, because it makes it much more difficult for a competitor to know whether its technology might be infringing. Smaller competitors (actual or potential) could be put out of business by litigation, and thus may choose to exit or not enter the market.

- Suppose you are sued for patent infringement. By holding a large portfolio of patents, you can more easily counter-sue (as Samsung has done against Apple). In fact, the credible threat of a counter-suit might be enough to avoid being sued in the first place.

Patent thickets have become increasingly important, but in fact have existed for some time. Here is the complaint of British firm engaged in processing sugar in 1865:

> "In the manufacture with which I am connected — the sugar trade — there are somewhere like 300 or 400 patents. Now, how are we to know all these 400 patents? How are we to manage continually, in the natural process of making

[3]Source: Thompson Reuters IP Monitor, September 2012.

> improvements in manufacture, to know which of these patents we are at any time conflicting with?"[4]

Patent Trolls. We have discussed the purchase and development of patent portfolios by large technology firms, but such portfolios are also bought or assembled by "nonpracticing entities," which are more commonly referred to as *patent trolls*. Patent trolls acquire patents with the simple objective of using them to sue other companies for infringement. The trolls typically acquire their patents from individual inventors or small companies, which they can easily locate via the Internet. They will then bring a lawsuit against a large operating company, and given the complexity of the technology and the risk of an adverse jury decision, the company will settle rather than fight the troll in court.

Patent trolls are becoming a growing drag on the development and adoption of new technologies. According to Hagiu and Yoffie (2013), "In 2001, nonpracticing entities brought 144 lawsuits targeting over 578 operating companies; by 2011, the numbers had increased to 1,211 lawsuits targeting 5,031 operating companies." Entering the "trolling business" is quite easy, and has been quite profitable. In 2006, for example, Research in Motion agreed to pay $612.5 million to a troll called NTP, which had sued RIM for infringing on eight wireless email patents.

3 The Option Value of Sleeping Patents

So far we have examined sleeping patents from a somewhat "anti-competitive" point of view, i.e., as a means of deterring entry. Now let us take a different and "pro-competitive" view of sleeping patents. Suppose we have a monopolist that has no concern about entry prevention (or alternatively, a group of firms that compete vigorously). Might the firm still want to do R&D to get a patent, and then let the patent sleep?

The answer may indeed be yes, once we start to think of a patent as an *option*. For most technologies and products, the R&D leading to a patent is typically much less costly

[4]R.A. Macfie, "Is the Granting of Patents for Inventions Conducive to the Interests of Trade?", *Transactions of the National Association for the Promotion of Social Science* 661, 665 (1865). My thanks to Bronwyn Hall for providing this example.

Table 1: The Connection Between a Patent and a Call Option

Stock option	Patent
Stock price	Value of plant to produce product
Exercise price	Cost of testing, marketing, building a plant
Variance of stock price	Variance of plant value
Dividend rate	Payout rate from plant
Time to expiration	Patent life
Value of option	Value of patent

than the development of the product itself. Pharmaceuticals provide a good example of this. The cost of the R&D required to develop a new compound, which would then be patented, is usually much less than the follow-on expenses required for testing and obtaining FDA approval, developing a full-scale production facility, marketing, etc. Furthermore, there is often considerable uncertainty about the future demand for the drug, in part because there is uncertainty about how many other drug companies will have similar drugs. Hence, we can view the patent as a call option. As with a financial call option, if the payout rate (which is the opportunity cost associated with waiting) is not too high, and if the variance of the underlying asset (the ability to produce and sell the drug) is sufficiently high, it will pay to wait rather than exercise this option immediately.

Hence, even in a very competitive environment, we would expect to see firms holding many patents, but letting most of them sleep, and only "exercising" (developing) a few of them. This is indeed what many drug companies do. They typically develop and bring to market only a small fraction of all the patents they have.

The close connection between a patent and a call option can be seen in Table 1. This option-like nature of patents (as well as unpatented technological know-how) has obvious implications for the valuation of high-tech (and other) companies. We would expect that a substantial portion of the market value of such companies is the option value associated with technological know-how, patented or otherwise. Furthermore, the greater the volatility and uncertainty in the company's markets, the greater should be the fraction of total market value that is due to option value. The reason is that with greater uncertainty, options are worth more, and the firm should be less willing to exercise those options (by installing physical capital to commercialize their technologies) rather than keeping them alive.

This is indeed what we find. Studies have been done that calculate the value of a company's installed capital and compare that value to total market value. This ratio is always less than 1, and is smaller the greater is the volatility and uncertainty associated with the company's core businesses. One study, for example, estimated the value of capital in place for 15 firms in 5 industries by capitalizing the implied flows of anticipated earnings, and found that it is half or less of market value in the majority of cases.[5] Furthermore, this fraction is only about 1/5 to 1/3 in industries where demand is more volatile (e.g., electronics and computers), but more than 1/2 in industries with less volatile demand (tires and rubber, food processing).

4 Discount Rates for Risky R&D

We have seen that patents can be viewed as options, and "sleeping patents" are just options that have not been (and may never be) exercised. It turns out that R&D itself has important option characteristics. The reason is that most R&D takes time and proceeds over several stages. Each stage of the R&D process provides the firm with an option to undertake the next stage. This has important implications for the decision to start an R&D project.

Suppose a firm is deciding whether to invest in a new and very risky R&D project. An example of such a project might be the development and testing of a new drug, the development of a new data compression method which may or may not work (and even if it

[5] See Carl Kester, "Today's Options for Tomorrow's Growth," *Harvard Business Review*, March/April 1984, 153–160.

does work, may or may not have a market), or early-stage oil and gas exploration in a new and uncharted area. A key element of this project is that there is a high risk of failure; it is unlikely you will end up with a commercially successful product. If you do succeed, however, the payoff will be very large. To keep things simple, we will assume that the risk of success or failure is completely diversifiable — there is no systematic risk until the actual sales of a commercial product (should you succeed). What discount rate should you use when deciding whether to begin the project? And what is the correct "beta" for the project?

Remember that the project is like a *compound option*: each stage, if successful, gives the firm an option to undertake the next stage. This in turn creates a leverage effect. This is illustrated below with a simple example.

Suppose the risk-free rate is $r_f = 5\%$ and the market risk premium is $r_m - r_f = 5\%$. Suppose that *if the project is successful* and thus generates net revenue, the beta for that net revenue is 1, so the discount rate is $r_{NR} = r_f + 1(r_m - r_f) = 10\%$. We have assumed that the R&D risk is completely diversifiable, so the discount rate for the cost of the R&D is $r_f = 5\%$. The NPV of the project is $PV_{NR} - PV_C$, so $PV_{NR} = PV_C + NPV$. Thus the expected return on PV_{NR} must equal a weighted average of the expected return on PV_C and the expected return on the NPV:

$$r_{NR}PV_{NR} = r_C PV_C + r^* NPV$$

Thus r^*, the expected return (and thus the discount rate) on the NPV is:

$$r^* = [r_{NR}PV_{NR} - r_C PV_C]/NPV$$

We can rewrite this as:

$$r^* = r_{NR} + (r_{NR} - r_C)\frac{PV_C}{NPV}$$

In most cases, $r_{NR} > r_C$, so that $r^* > r_{NR}$. If $PV_C >> NPV$, then $r^* >> r_{NR}$.

What is the equivalent β? Since $r^* = r_f + \beta(r_m - r_f)$, we have

$$\beta^* = (r^* - r_f)/(r_m - r_f)$$

Suppose $\beta_{NR} = 1$ so that $r_{NR} = r_m$. Then $r^* > r_m$ and $\beta^* > 1$. This is the *leverage effect. Note that it has nothing to do with any adjustment for the riskiness of the R&D.*

4.1 A Simple Example

Suppose we have a three-stage R&D project:

- **Stage 1**: At $t = 0$, spend \$10 million on R&D. The probability of success is 1/2. If this stage fails, stop. If it is successful, move on to
- **Stage 2**: At $t = 1$, spend \$30 million on the next stage of R&D. The probability of success is 1/2. If this stage fails, stop. If it is successful, move on to
- **Stage 3**: At $t = 2$ you have a commercial product that generates a stream of net revenues, with $\beta_{NR} = 1$ and $PV_{NR} = \$160$ million.

Now, let's examine the expected return (risk-adjusted cost of capital) and the equivalent β for each stage of this project.

Stage 1: In order to get net revenue, Stage 1 and Stage 2 must both be successful, and the probability of that happening is $(1/2)^2 = 1/4$. Thus at the beginning of Stage 1, the present value of future net revenue, the present value of cost, and the NPV are:

$$PV_{NR} = (\tfrac{1}{2})^2 \frac{160}{(1 + r_{NR})^2} = \frac{40}{(1.1)^2} = \$33.1M$$

$$PV_C = 10 + (\tfrac{1}{2})\frac{30}{1.05} = \$24.3M$$

$$NPV = 33.1 - 24.3 = \$8.8M$$

What is the cost of capital at Stage 1?

$$r_1^* = r_{NR} + (r_{NR} - r_C)\frac{PV_C}{NPV} = .10 + (.05)\frac{24.3}{8.8} = 23.8\%$$

What is the equivalent β for Stage 1?

$$r_1^* = r_f + \beta_1(r_m - r_f) = .05 + .05\beta_1$$

Rearranging:

$$\beta_1 = (.238 - .05)/.05 = 3.76$$

Note that these relatively high values for r_1^* and β_1 are due to the leverage effect, and *not* to the riskiness of the R&D itself.

Stage 2 (Assuming Stage 1 is successful): The present values are now:

$$PV_{NR} = (\tfrac{1}{2})\frac{160}{1.1} = \$72.7M$$

$$PV_C = \$30M$$

$$NPV = 72.7 - 30 = \$42.7M$$

What is the cost of capital at Stage 2?

$$r_2^* = .10 + (.05)\frac{30}{42.7} = 13.5\%$$

What is the equivalent β for Stage 2?

$$\beta_2 = (.135 - .05)/.05 = 1.70$$

Stage 3: If Stage 1 and Stage 2 are both successful, production and sales begin in Stage 3. At this point there is no leverage; the discount rate is simply $r_3^* = 10\%$ and the equivalent β is $\beta_3 = 1.00$.

4.2 Questions:

Table 2 shows recent estimates of equity betas for several firms that are heavily engaged in R&D. Here are a few questions about the numbers:

- Merck has been developing a large number of new molecules. Why is its equity beta below 1?

- Celldex Therapeutics is a small company engaged in Phase I trials of an experimental oncology drug. ImmunoGen is also a small company, doing early-stage research on antibody drugs for oncology. Are the betas for these companies roughly what you would expect?

Table 2: Some Recent Estimates of Equity Betas

Company	Beta	Market Cap.
Merck	$\beta = 0.8$	\$200B
ImmunoGen, Inc.	$\beta = 2.6$	\$0.5B
Celldex Therapeutics, Inc.	$\beta = 3.0$	\$0.4B
Foundation Medicine, Inc.	$\beta = 0.6$	\$1.4B

- Foundation Medicine collects genomic information from cancer patients, which it sells to biopharmaceutical companies that are developing targeted oncology therapies. Its revenues are driven by a strong network externality, because as its database grows, it can identify an increasing number of genetic characteristics that can be associated with specific types of cancer, making its data more and more valuable to client companies. Is this business model consistent with a beta well below 1?

- In our simple example, the NPV at Stage 1 was positive but small. Would this be representative of a typical startup project?

5 Patent Licensing

We turn now to the question of patent licensing. When should a company license its technology to other firms, rather than retain the possibility of holding on to a monopoly position? As a general matter, one would expect to see widespread licensing, because it is often a way of creating "gains from trade." For example, a firm might be able to expand the market for a product by licensing it to other firms, or might not have the marketing and/or production capabilities of other firms. In addition, we have seen that in markets with strong network externalities, there are incentives to license in order to avoid a costly battle over a standard. Thus, Philips agreed on a compact disk standard with Sony, and licensed the technology to other firms, thereby avoiding a standards battle.

Here we examine two additional reasons for licensing. First we will see that the licensing of a technology might move a market in which two or more firms have been competing aggressively to something closer to a monopoly. Second, we will see how licensing can be used as a way to help promote the adoption of a new technology: by sending a credible signal that prices will remain low, so that it is worthwhile for consumers to invest in the sunk costs needed to adopt the technology.

5.1 Patent Licensing to Reduce Competition

Suppose that you and a competitor both produce and sell mousetraps and, sadly, you compete aggressively with each other. Both of you produce nearly identical mousetraps, so your prices are the same. You have just invented a new *digital* mousetrap. Unfortunately, these digital mousetraps catch the same number of mice per day as the old analog mousetraps, and they are just as costly to manufacture. In other words, your invention seems to have *no social value*. But might it have some private value?

The answer is yes. Suppose you license this technology to your competition, using a two-part tariff. By structuring the license properly, you can induce your competitor to switch to your technology, and you cause industry output to drop close to the monopoly level.[6]

To keep this as simple as possible, we will use the example of Cournot equilibrium in Chapter 12 of Pindyck & Rubinfeld, *Microeconomics*. Suppose you and your competitor face the following market demand curve:

$$P = 30 - Q$$

where $Q = Q_1 + Q_2$ is total production. We will assume that both firms have zero marginal cost (for producing analog or digital mousetraps). Remember that in a Cournot equilibrium, each firm sets its own output taking the output of its competitor as fixed. In this case you can verify that your (Firm 1's) reaction curve is

$$Q_1 = 15 - \tfrac{1}{2}Q_2$$

[6] This example is based on Carl Shapiro, "Patent Licensing and R&D Rivalry, *American Economic Review*, May 1985, 25–30.

and your competitor's (Firm 2's) reaction curve is

$$Q_2 = 15 - \tfrac{1}{2}Q_1$$

Thus the Cournot equilibrium is $Q_1 = Q_2 = 10$, price is \$10, and profits are $\pi_1 = \pi_2 = \$100$. By comparison, the *collusive* (i.e., monopoly) output level is $Q = 15$, so that $P = \$15$ and $\pi_1 = \pi_2 = \$112.50$.

Is there a way to get to this collusive output level without colluding? Suppose Firm 1 licenses its digital technology to Firm 2. Like most patent licenses, this license uses a two-part tariff with a fixed fee T and a royalty rate R. How should we choose T and R?

Begin with R. Firm 2's profit is now

$$\begin{aligned}
\pi_2 &= P(Q)Q_2 - RQ_2 \\
&= (30 - Q_1 - Q_2)Q_2 - RQ_2 \\
&= 30Q_2 - Q_1Q_2 - Q_2^2 - RQ_2
\end{aligned}$$

To get Firm 2's reaction curve, maximize π_2 with respect to Q_2:

$$\frac{\partial \pi_2}{\partial Q_2} = (30 - R) - Q_1 - 2Q_2 = 0$$

so that

$$Q_2^* = 15 - \tfrac{1}{2}R - \tfrac{1}{2}Q_1$$

Now consider Firm 1's profit, which is

$$\begin{aligned}
\pi_1 &= P(Q)Q_1 + RQ_2 \\
&= 30Q_1 - Q_1^2 - Q_1Q_2 + RQ_2
\end{aligned}$$

Maximize this with respect to Q_1 to get Firm 1's reaction curve:

$$\frac{\partial \pi_1}{\partial Q_1} = 30 - 2Q_1 - Q_2 = 0$$

so that

$$Q_1^* = 15 - \tfrac{1}{2}Q_2$$

To get the Cournot equilibrium, combine these two reaction curves:

$$Q_1 = 10 + \tfrac{1}{3}R$$

$$Q_2 = 10 - \tfrac{2}{3}R$$

Now pick R to maximize Firm 1's profit:

$$\begin{aligned} \pi_1 &= P(Q)Q_1 + RQ_2 \\ &= 100 + \tfrac{50}{3}R - \tfrac{5}{9}R^2 \end{aligned}$$

$$\frac{\partial \pi_1}{\partial R} = \frac{50}{3} - \frac{10}{9}R = 0$$
$$R^* = \$15 \text{ per unit.}$$

In this case $Q_1^* = 10 + 5 = 15$, and $Q_2^* = 10 - 10 = 0$. The price is $P = \$15$ (the monopoly price), and $\pi_1 = \$225$.

But how can we get Firm 2 to take this license and adopt the digital technology? The answer is to make the fixed fee T *negative*. For example, if we set $T = -\$101$, Firm 2 will earn 1 dollar more than before, and Firm 1 will have a net profit of \$124. Not bad for a worthless technology!

Figure 5 illustrates what is going on. By setting a high enough royalty, we can shift Firm 2's reaction curve sufficiently to the left so that it intersects Firm 1's reaction curve at the collusive output level.

You might raise the objection that this is just a ploy that will lead to an antitrust violation. But remember that in the real world, the new technology is likely to have some positive value, *so that a negative fixed fee T will not be necessary*. (As we all know, digital mousetraps are, in fact, much more efficient than analog mousetraps.) You should understand the basic principle—by licensing to a competitor, you can alter the competitive equilibrium to one that is more favorable. You do this by raising the competitor's marginal cost via the royalty rate R.

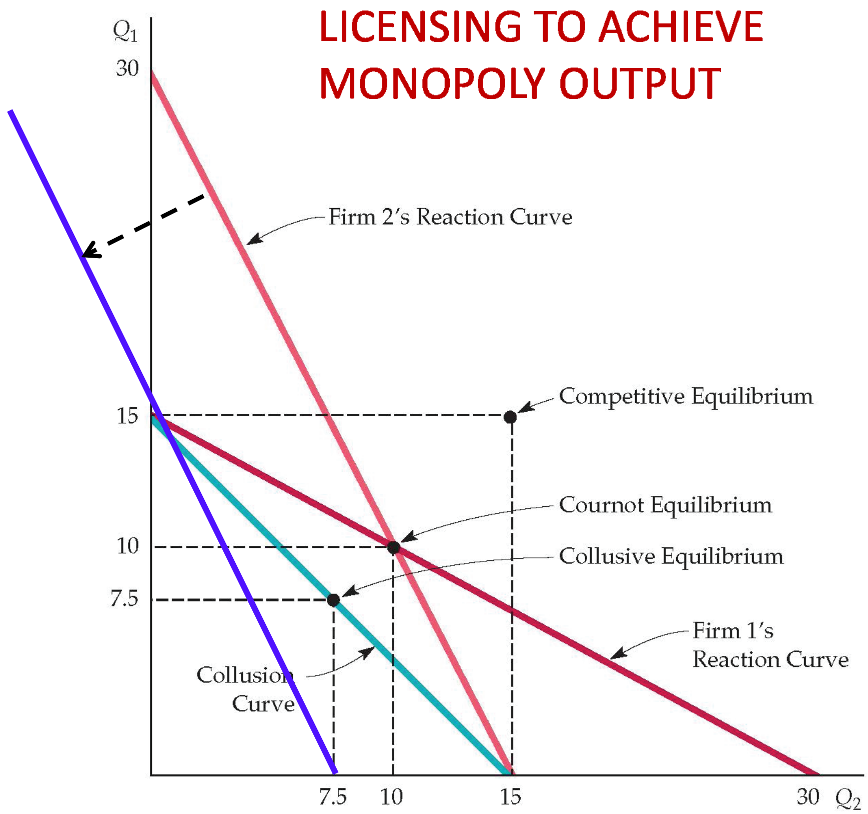

Figure 5: Duopoly Example

5.2 Cross Licensing

Firms can also license to each other as a way of creating a more favorable competitive equilibrium. Returning to our example of digital mousetraps, suppose once again that two firms compete in the mousetrap market, and *both* have been developing digital technologies. In fact, each firm has developed its own "module" that can be used as part of the digital mousetrap design.

Suppose that the two firms arrive at a cross-licensing agreement, whereby Firm 1 licenses its module to Firm 2, charging a royalty R_1, and Firm 2 licenses its module to Firm 1, charging royalty R_2. We'll asume that the market demand and costs are the same as they were before.

Each firm chooses its royalty rate optimally but non-cooperatively. Firm 2's profit is now

$$\pi_2 = P(Q)Q_2 - R_1Q_2 + R_2Q_1$$

$$= (30 - Q_1 - Q_2)Q_2 - R_1Q_2 + R_2Q_1$$

Maximizing π_2 with respect to Q_2 gives Firm 2's reaction curve:

$$Q_2^* = 15 - \tfrac{1}{2}R_1 - \tfrac{1}{2}Q_1$$

Likewise, for Firm 1:

$$Q_1^* = 15 - \tfrac{1}{2}R_2 - \tfrac{1}{2}Q_2$$

We can now solve these two equations for Q_1 and Q_2:

$$Q_1 = 10 + \tfrac{1}{3}R_1 - \tfrac{2}{3}R_2$$

$$Q_2 = 10 + \tfrac{1}{3}R_2 - \tfrac{2}{3}R_1$$

We now turn to the choice of royalty notes, R_1 and R_2. Firm 1 picks R_1 to maximize its profit, and Firm 2 picks R_2 to maximize its profit. Firm 1's profit is:

$$\pi_1 = P(Q)Q_1 + R_1Q_2 - R_2Q_1$$

Substitue $Q_1(R_1, R_2)$ and $Q_2(R_1, R_2)$ into this expression, to get $\pi_1(R_1, R_2)$. Then, maximize $\pi_1(R_1, R_2)$ with respect to R_1, holding R_2 fixed. The result is:

$$R_1^* = 15 - \tfrac{1}{10}R_2$$

Likewise for Firm 2:

$$R_2^* = 15 - \tfrac{1}{10}R_1$$

Finally, combine these two equations to solve for R_1 and R_2:

$$R_1^* = R_2^* = 13.64$$

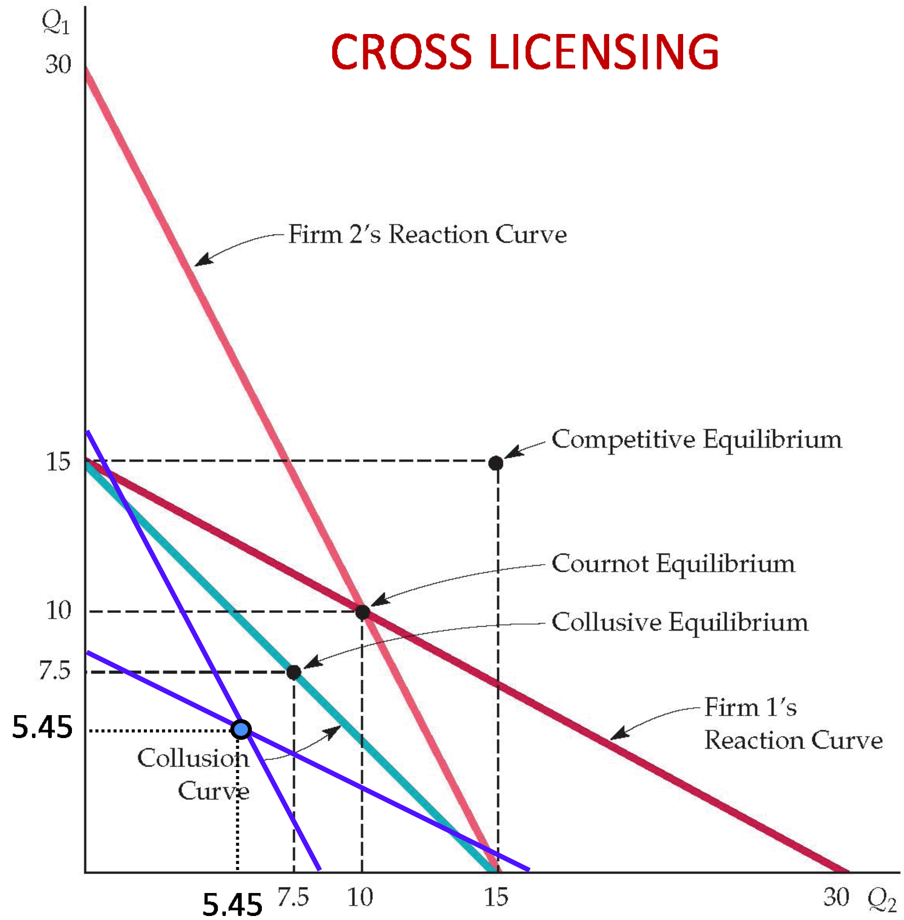

Figure 6: Example of Cross-Licensing

These royalty rates result in $Q_1^* = Q_2^* = 5.45$, and $P = \$19.10$. Also, $R_1^* Q_2^* = R_2^* Q_1^*$, so the royalty payments and receipts cancel out. The profits to the two firms are $\pi_1 = \pi_2 = \$104.10$. Note that this is better than the profits resulting under the original Cournot equilibrium ($\pi_1 = \pi_2 = \$100$), but not as good as the profits that would result if the firms could behave cooperatively, ($\pi_1 = \pi_2 = \$112.50$). These results are illustrated in Figure 6.

Now compare these results to those in the previous case where only Firm 1 licenses to Firm 2. You can see that although the two firms benefit from this cross-licensing arrangement, unless the technologies are actually productive, consumers are much worse off — output is sharply lower, and the price is much higher. The firms benefit because they have imposed a large royalty on each other, raising each other's marginal cost (even though the firms receive equal royalty payments from each other).

5.3 Patent Licensing As a Signal of Low Prices.

Now let's examine a second and very different motivation for licensing—it can be a way to send a credible signal to consumers that they will not be forced to pay very high prices after they have invested the sunk costs needed to adopt a new technology. We can illustrate this problem using a simple example.

Suppose you are a monopolist offering new process technology that you have developed and patented. The technology can be used over three years, and we will ignore discounting. The prices you charge for the technology are P_1 in the first year, P_2 in the second year, and P_3 in the third year. In addition, each buyer would have to spend a one-time sunk cost of S to switch to your technology. Alternatively, the buyer could stick with the old technology, at an ongoing cost of C per year.

A buyer must decide whether to buy your new technology. Doing so would make sense if the total cost of switching and using the new technology is less than the cost of sticking with the old technology. Thus switching makes sense if:

$$P_1 + P_2 + P_3 + S < 3C \tag{7}$$

If the potential buyer knew P_1, P_2, and P_3, deciding whether to switch would be straightforward. The problem is that the buyer might know P_1 (presumably you have already announced that), but doesn't know what P_2 and P_3 will be.

In fact, the buyer has good reason to worry about what P_2 and P_3 will be. Once the buyer has paid the sunk cost S, the seller of the new technology will have an incentive to set P_2 and P_3 just below C. The buyer will then use the new technology in years 2 and 3, but will end up paying more over the three years than he would have had he simply stayed with the old technology. This is the "holdup" problem. Knowing this, the potential buyer won't switch to the new technology.

Let's throw in some numbers to see how this works. Suppose $C = \$200{,}000$, $S = \$300{,}000$, and the seller, feeling generous today, sets $P_1 = 0$. This sounds good, so we spend \$300,000 to switch and use the new technology in year 1.

But what happens next? In years 2 and 3, the seller can charge $P_2 = P_3 =$ \$200,000, and our total expenditure over the three years will be

$$P_1 + P_2 + P_3 + S = \$700,000 > 3C$$

Thus we would regret having paid the sunk cost of \$300,000. But we know in advance that this will happen, so we won't buy the new technology in the first place.

MRI Imaging. Where might the numbers in this little example come from? Think about a hospital's decision to buy or lease an MRI machine. The hospital might currently lease an MRI machine that gives it MRI imaging capability at a cost of $C =$ \$200,000 per year. However, the hospital has the option to replace this with a (refurbished) machine for $S =$ \$300,000. With a maintenance cost (parts and service) of $P_1 = P_2 = P_3 =$ \$100,000 per year, the hospital would come out ahead over three years. The problem is that while $P_1 =$ \$100,000 is known, the seller has an incentive to raise the maintenance cost in years 2 and 3.

The problem here is "holdup." The buyer needs some assurance that the prices P_2 and P_3 will remain low, but knows that the seller will have an incentive to raise those prices. What can be done in this case? There are several possibilities:

- Have the supplier bear part of the adoption cost S, thereby lowering the effective adoption cost so it is less than C.

- The seller might "commit" to a low price in years 2 and 3 through a long-term contract. (However, such contracts can be difficult to write and enforce.)

- Alternatively, the supplier and the buyer might engage in a long-term relationship, or even vertically integrate, as a way of ensuring that prices in the future will be low. Note that this is another potential benefit of vertical integration — it can avoid the "holdup" problem. But as we have seen, vertical integration has other problems, and is not always feasible. A long-term relationship is likely to be easier, and is what we often observe.

- Another alternative is to license the technology in order to establish second sources, and thereby commit to a competitive market and hence lower prices in years 2 and 3.

I will focus on this last alternative, licensing the technology. To see how it would work, let's return to our simple example in which $C = \$200,000$ and $S = \$300,000$. Consider what happens if the supplier maintains a monopoly in year 1, but licenses the technology so that the market will be competitive in years 2 and 3, driving the prices in those years down to $P_2 = P_3 = \$75,000$. In this case, in the first year the supplier can charge up to

$$P_1 = 3C - S - P_2 - P_3 = \$600,000 - \$300,000 - \$150,000 = \$150,000 \ .$$

The supplier would receive a total of \$150,000 + \$75,000 + \$75,000 = \$300,000, whereas without licensing it could not sell the technology and would get nothing.

This incentive to license can be even stronger when there are network externalities. Suppose there is a strong positive network externality, so that consumers are inclined to buy a product only if they expect that a large number of other consumers will also buy the product in equilibrium. A monopolist producer of the product would therefore want to be able to credibly commit to producing a large output (which means a low price), so that consumers would expect a high level of total sales in equilibrium. But making a credible commitment of this sort would be difficult. A monopolist that simply promised to produce a large amount of output would not be believed, because he will always have the incentive later to exercise his monopoly power by reducing output for any given level of consumers' expectations.

Licensing provides a way around this problem. By providing the technology to competitors, the monopolist gives away part of its monopoly power, but in return is able to credibly signal to consumers that prices in the future will be low, so that there will indeed be a large network of users.[7] Recall that this is what happened after Philips and Sony agreed to adopt the same technology for compact discs, and then decided to license the technology broadly to any firms that wanted to produce compact disc players. By doing so, they sent a

[7] For an analytical treatment of the ways in which network externalities make licensing desirable, see N. Economides, "Network Externalities and Invitations to Enter," Stern School of Business, New York University, January 1992.

credible signal to music companies that compact disc players would be produced and sold at relatively low prices, so that the music companies could conclude that sunk cost investments in disc-pressing facilities made sense.

6 Other Objectives of Patent Licensing

Suppose that you have developed and patented a new digital toaster. You could simply produce and sell the toasters yourself, rather than involve any other firm. However, you may not be as good at producing (never mind marketing) digital toasters as you are at inventing them. As we explained earlier, we would generally expect to see widespread licensing because it is a way of creating "gains from trade." Very often, other firms can provide important inputs or know-how such that everybody benefits from a licensing arrangement.

Some of the other potential benefits of patent licensing can be summarized as follows:

1. Licensing can provide a way of controlling existing competitors. As we saw with our digital mousetrap example, a royalty arrangement based on a two-part tariff can be used to reduce industry output closer to monopoly levels. Another example of this was the decision of Genentech to license their patent for synthetic insulin. Genentech developed synthetic insulin in the late 1970s. Genentech could have produced and sold the synthetic insulin itself, but instead it licensed the patent *exclusively* to Eli Lilly, which at the time was the incumbent monopolist producer of insulin. Why did Genentech do this? Because the post-innovation monopoly profits were greater than the sum of duopoly profits, so that both firms gained considerably from licensing.

2. Licensing can also be used to deter or limit competition in other ways. Licensing a patent, for example, will reduce the incentive of other firms to "design around" it, or to develop an even better technology that leapfrogs the original patent. Thus, in the mid-1980s, Compaq Computer licensed its "Roberts patent," which at the time was crucial for the operation of a computer monitor, to any other computer companies that wanted it.[8]

[8]Compaq developed and successfully sold the first "compact" or "luggable" computers, which in the

3. We saw before that in some cases a company will want to license a patent in order to *create* competition, rather than reduce it. In particular, we saw that this provides a means of signalling low prices in the future, so that buyers will have the incentive to pay the sunk costs needed to adopt the new technology. Another reason for creating competition is to allow *multiple sourcing.* In some industries, a firm may not want to adopt a technology if it means becoming dependent on a single source. Licensing the technology to several different producers alleviates this problem.

4. Licensing can also be used to create or promote a standard. As we discussed earlier, Philips agreed on a compact disk standard with Sony, and licensed the technology to other firms, thereby avoiding a standards battle of the sort that occurred with Beta and VHS in video cassette recorders.

Often, two or more of these benefits or objectives will apply in a particular licensing situation. It is important to understand what, specifically, you are striving for when licensing a patent. It is also important to understand some of the potential problems that can arise:

1. Often, the licensor and licensee must negotiate in the presence of asymmetric and/or incomplete information. Both parties may disagree over the value of a license, which can make it difficult to strike a deal.

2. Licensing can reveal part of a company's vital technological information, know-how, and trade secrets. For a license to be useful, it must often be accompanied by detailed technical specifications and other information. This might make it easier for the licensee to "leapfrog" the licensor at some future point in time.

3. It may be difficult to monitor the licensee's output and sales. Monitoring is necessary in order to collect royalties. Then, why not just use a fixed fee instead of a royalty? I think you know the answer to that question.

beginning (1984) weighed 30 to 34 pounds. Among its features, the 5-inch display could show text and graphics. The early IBM PCs required separate monitors for text and graphics. Compaq's patent made it possible to display text and graphics on the same monitor. In 2002, Compaq was acquired by HP.

7 Complementary Patents and Patent Pools

Complementary patents are patents that must be used together to have any real value. An example would be the various patents (developed by different companies over the years) that apply to input-output operations, data buffering, synchronization, etc. on the mother board of a typical computer. Complementary patents have become particularly important with the explosive growth of "systems on a chip" (SOCs). When developing an SOC, a company like Motorola or Cadence Design Systems will typically buy or license "intellectual property blocks" (IP blocks) from companies like Rambus. These IP blocks are useless by themselves; they only have value when used together to produce an SOC for, say, a cellular telephone. (See Figure 7.)

Merchant IP. When the development of a product involves large numbers of complementary patents, licensing problems can become very difficult. The reason is that it is hard to assign value to specific patents, and to negotiate revenue-sharing arrangements via licensing terms. Valuing IP blocks has become increasingly important with the growth of "merchant IP."

Starting around 2000, SOC design and manufacturing experienced huge growth. Small companies (some of which grew to become large companies) would innovate by developing IP blocks that, when embedded in silicon, would perform a particular function. For example, an IP block might regulate signal output (and thus power consumption) for a cell phone or other device. For an SOC designer, it was much cheaper to license the IP blocks it needed, rather than try to develop each function by itself. Thus a market developed in which SOC designers would shop around for IP blocks, and then license those blocks for their own use. That market is often referred to as "'merchant IP."

The problem is that the owner of each IP block will insist on the highest royalty possible, especially if that IP block is unique. The problem is analogous to double marginalization, but much worse because the patent-holders will try to squeeze out as much monopoly profit as possible for each of five or ten IP blocks. (We might call this "multiple marginalization.") In the context of Figure 7, the owner of Block A will claim that it is the most important, and so will the owners of Blocks B, C, and D. The result can be a breakdown in the market. As a result, in recent years an alternative arrangement has become increasingly popular.

Patent Pools. Starting in 1995, the U.S. government allowed firms to form *patent pools*.[9] The idea is that (possibly competing) firms would pool their complementary patents so that they had joint ownership of them. The terms for this joint ownership are established ex ante, before the set of patents (or perhaps certain subsets of the patents) are licensed as a "package" to other firms. Some of the more well-known patent pools include the "Bluetooth pool" and the "MPEG-4 pool." The Bluetooth pool created a Bluetooth standard, and brought together patents from 12 companies including Ericsson, IBM, Intel, and Motorola. The pool for MPEG-4 (a method for compressing audio-visual data) has patents from 29 companies.

Note that the joint ownership of the patent pool has the potential for creating market power if some of the patents are substitutes rather than complements, so this naturally creates antitrust concerns. Firms that want to pool their patents must therefore apply to do so. So far, however, almost all applications for patent pooling have been approved. The reason is that without patent pooling, the market for IP blocks can stop functioning, threatening innovation, and raising the costs of developing SOCs. Although patent pooling has become increasingly popular in the United States, it has not had as much of an impact in Europe. The European Commission is still trying to decide how to deal with it.

What if companies pool patents that are actually substitutes, rather than complements, as a way of gaining market power? The companies would have to apply to the DOJ for permission to form the pool, but it would be very hard for the DOJ to determine whether the patents at issue are actually complements or substitutes. Fortunately, patent law in the U.S. (and in Japan) prevents this from becoming a problem. In the U.S. and Japan, a company that owns a patent *must retain ownership of the patent when licensing it.* This means that the company retains its right to license the patent to others. (When granting

[9]Patent pools existed during the 19th century. One of the first was the "sewing machine pool," a set of patents that, when used together, made it possible to manufacture the earliest sewing machines. But patent pooling largely stopped in the early 20th century as a result of the passage and enforcement of the antitrust laws.

the right to form a patent pool, the DOJ will require the licenses to be non-exclusive, so that the company can always license the patent to another firm outside the pool.) As a result, if the patents are substitutes and the pool tries to exercise market power by raising prices (i.e., raising royalty rates), individual patent holders can easily undercut the pool by licensing outside the pool.

Patent pooling does not eliminate all of the information problems discussed above. Different firms could have very different views regarding the relative value of the various patents that are going into the pool. However, if the complementarities are strong, it is typically much easier to negotiate a revenue-sharing arrangement for the licensing of the pool than it is to negotiate a licensing arrangement for each patent individually. Assuming the antitrust problems are not too severe, pooling provides a mechanism for enhancing the efficiency and gains from trade from patent licensing.

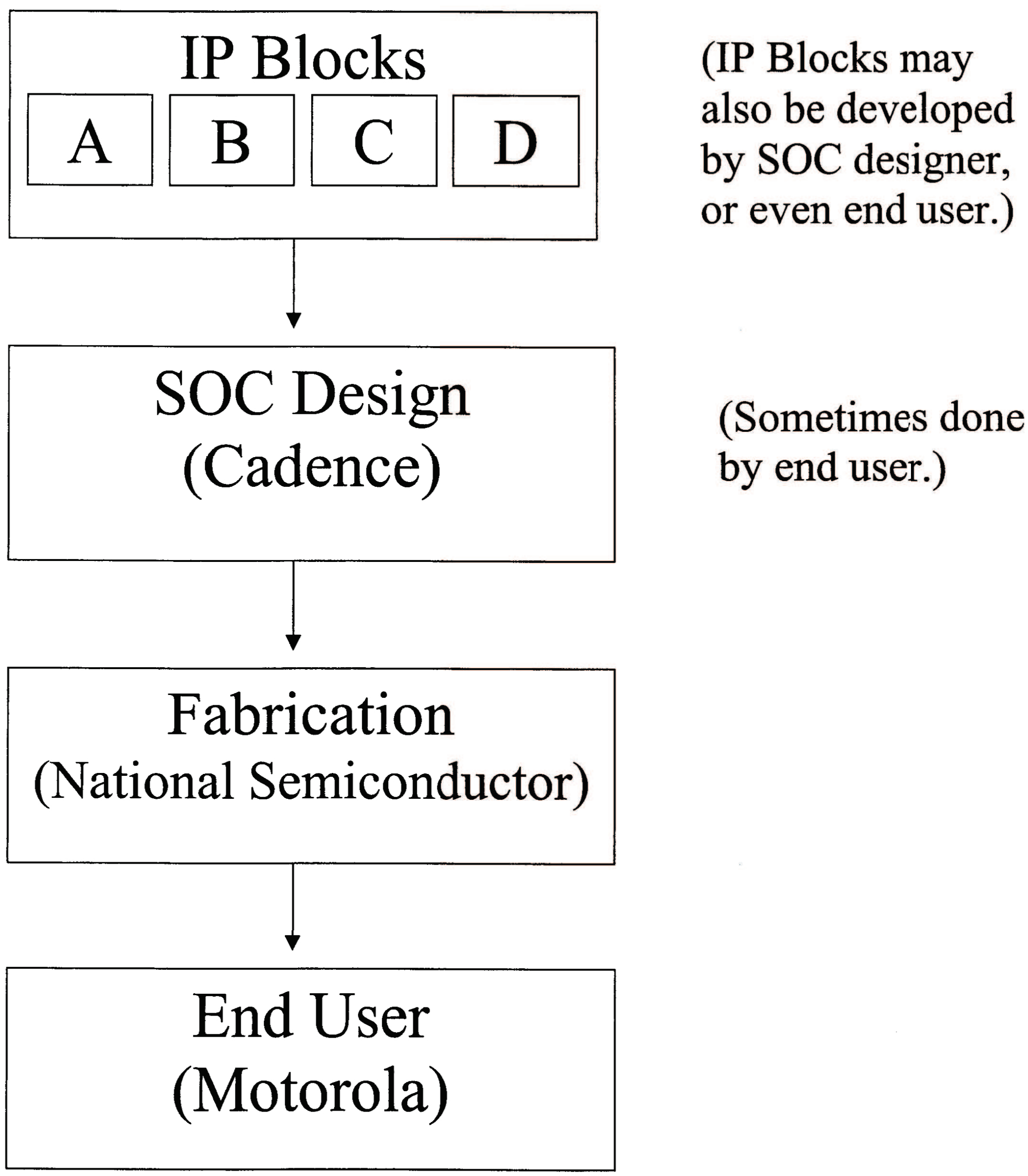

Figure 7: Systems on a Chip (SOC) — Vertical Structure