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Intellectual Property as a Carrot for Innovators

Using Game Theory to Show the Limits of the Argument

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Using Game Theory to Show the Limits of the Argument*

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Abstract

Policymakers all over the world claim: no innovation without protection. For more than a century, critics have objected that the case for intellectual property is far from clear. This paper uses a game theoretic model to organise the debate. It is possible to model innovation as a prisoner's dilemma between potential innovators, and to interpret intellectual property as a tool for making cooperation the equilibrium. However, this model rests on assumptions about cost and benefit that are unlikely to hold, or have even been shown to be wrong, in many empirically relevant situations. Moreover, even if the problem is indeed a prisoner's dilemma, in many situations intellectual property is an inappropriate cure. It sets incentives to race to be the first, or the last, to innovate, as the case may be. In equilibrium, the firms would have to randomise between investment and non-investment, which is unlikely to work out in practice. Frequently, firms would have to invent cooperatively, which proves difficult in larger industries.

Keywords: intellectual property, game theory
JEL: C72, O31, K11

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1. The Political Force of the Argument

Words are a source of power. Successful policymakers are able to present regulatory intervention as the logical response to a publicly perceived problem. Intellectual property intensely intervenes into freedom and property. Those who have not been licensed are enjoined from using the idea. This even holds if they have lost a patent race, i.e. if the idea is their own. From the beginning, those in favour of intellectual property have brought forward an incentive argument: no innovation without protection. It is to be found in the official documents of the US Patent and Trademark Office

> "Growing global trade in pirated and counterfeit goods threatens America's innovation economy, the competitiveness of our leading companies and small manufacturers, and the livelihoods of their workers."[1]

EU directives follow suit:

> "If authors or performers are to continue their creative and artistic work, they have to receive an appropriate reward for the use of their work, as must producers in order to be able to finance this work. […] Adequate legal protection of intellectual property rights is necessary in order to guarantee the availability of such a reward and provide the opportunity for satisfactory returns on this investment."[2]

The theoretical, empirical and political debate on the issue dates back to the 19th century (Machlup and Penrose 1950; Hadfield 1992). Entire libraries have been written on the topic. Excellent surveys are available (Machlup 1958; Towse and Holzhauer 2002; Federal Trade Commission 2003; Scotchmer 2004; Menell and Scotchmer 2005). This paper does not intend to add to this literature. It does not try to be comprehensive. All it sets out to do is this: it uses a simple game theoretic model to present the key arguments from this discussion in a consistent form.

Section 2 tells a coherent story of why intellectual property is indeed necessary to bring about innovation. Section 3 shows how this argument rests on assumptions about the nature of the problem that are not likely to be true in many plausible situations. Section 4 demonstrates that there are important situations where intellectual property is not necessary for innovation, or where it is even counterproductive, even if one believes in the underlying definition of the problem. Section 5 drops two assumptions inherent in the original model. The demand side is explicitly modelled. And the possibility is introduced that two firms simultaneously invest, but ultimately only one of them gets the property right. Section 6 concludes.

2. The Incentive Story

It is possible to conceptualise the problem of innovation in a way (subsection 2.1) that makes intellectual property the natural solution (subsection 2.2).

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1 http://www.uspto.gov/main/profiles/stopfakes.htm.

2 Directive 2001/29/EC of 22 May 2001 on the Harmonisation of Certain Aspects of Copyright and Related Rights in the Information Society, al. 10.

2.1 A Model of the Innovation Problem

In essence, innovation is about ideas. To generate new ideas, resources must be invested. For most innovations, human capital—i.e. researchers—is not enough. They must also receive technical and administrative support; they need a laboratory and a library; they must travel to meet their peers; the feasibility of their ideas must be tested in real-life settings. Researchers themselves may often well be intrinsically motivated, so that (financial) incentives are not necessary, and they may even be counterproductive (Frey 1997). However, for the professional environment, intrinsic motivation is much less likely to work.

The fact that financial resources are needed does not in and of itself cause a problem. If nobody else is interested in the idea, the resources are correctly allocated. The resources invested depend on the willingness to pay of those working on the idea. However, most ideas are of interest to outsiders. Competitors are also able to reduce their production costs if they exploit a process innovation. Competitors and the demand side of the market increase their utility if they rely on an idea that led to a product innovation. In order to make the presentation of the argument more transparent, the demand side is neglected at this point. It is considered in Section 5.

If outsiders have an interest in the idea, innovation has a positive externality. It is due to the fact that ideas are pure public goods. Once the idea is publicly available, nobody can be prevented from exploiting it. If one person relies on the idea, this does not make the idea less valuable. Neither exclusion nor rivalry in consumption is present. Public goods theory predicts that such goods will not be provided in the socially desirable quantity. If the individual benefit is below the cost, the good will not be provided at all (Cornes and Sandler 1996).

This prediction is based on a game theoretic model. The relationship between the innovator and all outsiders is conceptualised as a prisoner's dilemma (for a similar, but less comprehensive approach, see Gordon 1992). As long as those interested in the innovation stand no chance of forming coalitions, a two-person model suffices. It describes the interaction between the potential innovator and every single person interested in the innovation.

In this model, there are four situations: I invest, but my interaction partner does not. Denoting investment as cooperation C, and non-investment as defection D, this situation may be written as CD. By the same token, the situation where my interaction partner invests, but I do not, is denoted as DC. In situation CC, we both invest. In situation DD, neither of us does. Note that, in the baseline model, if we both invest, this means there is cooperative research. This assumption is dropped in Section 5.

Since we are in a situation of strategic interaction, my payoff not only depends on what I do, but also on what my interaction partner does. The model assumes that we take these decisions simultaneously. There is thus no planning meeting where we write a joint production plan. Alternatively, one may interpret the model as saying that, absent intervention from the legal order, promises made at such planning meetings would not be credible (Heckathorn 1989). Given these assumptions, payoffs may be defined as in Table 1. Since the game is fully symmetric, it suffices to define payoffs for one of the agents.

	benefit	cost	payoff	rank
DC	b	0	b	3
CC	b	-c	b-c	2
DD	0	0	0	1
CD	b	-2c	b-2c	0

Table 1
Baseline Model: Payoffs

The game is a prisoner's dilemma if payoffs are indeed ranked as in Table 1. This is the case if the following holds:

DC > CC: b>b-c, which is true if c>0
CC > DD: b-c>0, which is true if c<b
DD > CD: 0>b-2c, which is true if b<2c

A further condition is

$$CC \geq \frac{DC + CD}{2}$$

(Rapoport and Chammah 1965), which is true since

$$b - c = \frac{2b - 2c}{2}$$

If parameters are specified as indicated, this constitutes the game as in Table 2. In this table, payoffs are represented by their ranks to make it easier to see the strategic implications.

	C	D
C	2,2	0,3
D	3,0	1,1

Table 2
Baseline Model

Excluding dominated strategies, or looking for the Nash equilibrium, one finds the only equilibrium in the DD cell. In equilibrium, neither firm invests in innovation. This is a dilemma since, by investing, both firms would be individually better off. Strategic interaction prevents them from getting at the Pareto superior solution. This is due to a combination of greed and fear. Greedy firms prefer their individually best outcome (in the DC cell) over their individually second-best outcome (in the CC cell). Fearful firms preempt this by themselves defecting (Macy and Flache 2002).

2.2 Intellectual Property As the Solution

If the legal order grants the inventor a property right, outsiders are no longer able to exploit the idea, unless the inventor allows them to do so. The property right thus allocates bargaining power. The innovator is able to make a take-it-or-leave-it offer. The strategy space of the firms is extended to giving or buying licences. This is denoted the following way: as before, either firm may invest (I), or not (~~I~~). If only one firm invests, the other may decide to buy a licence (L) or not (~~L~~). This makes for payoffs as in Table 3.

	benefit	cost	licence	payoff	rank3
IIL	b	-2c	L	b-2c+l	4
II	b	-c	0	b-c	3
IIL	b	0	-i	b-l	2
II	0	0	0	0	1
IIL	0	0	0	0	1
IIL	b	-2c	0	b-2c	0

Table 3
Impact of Property Right on Payoffs

The ranking as in this table presupposes

I~~I~~L > II: b-2c+l>b-c = l>c

II > ~~I~~IL: b-c>b-l = l>c

~~I~~IL > ~~II~~: b-l>0 = b>l

~~I~~I~~L~~ > I~~IL~~: 0>b-2c = 2c>b

The assumption that 2c>b was already present in the original model. l>c implies that buying a licence is more expensive than contributing to cooperative innovation. b>l implies that outsiders want to buy a licence from the innovator.

In this model,[4] trading a licence is an option only if one firm has innovated and the other has not. Consequently, the firms no longer play a simultaneous game. When deciding whether to buy a licence, firm 2 knows whether firm 1's innovative efforts have been successful. Figure 1 has the game tree of the resulting game.

3 In the baseline model, ranks would also do for the extended model. In later sections, however, equilibria in mixed strategies play a role. Calculating the equilibrium probabilities, one needs absolute, not only relative payoffs. This is why, in the extended model, ranks are no longer presented.

4 On patent races, see below, Section 5.

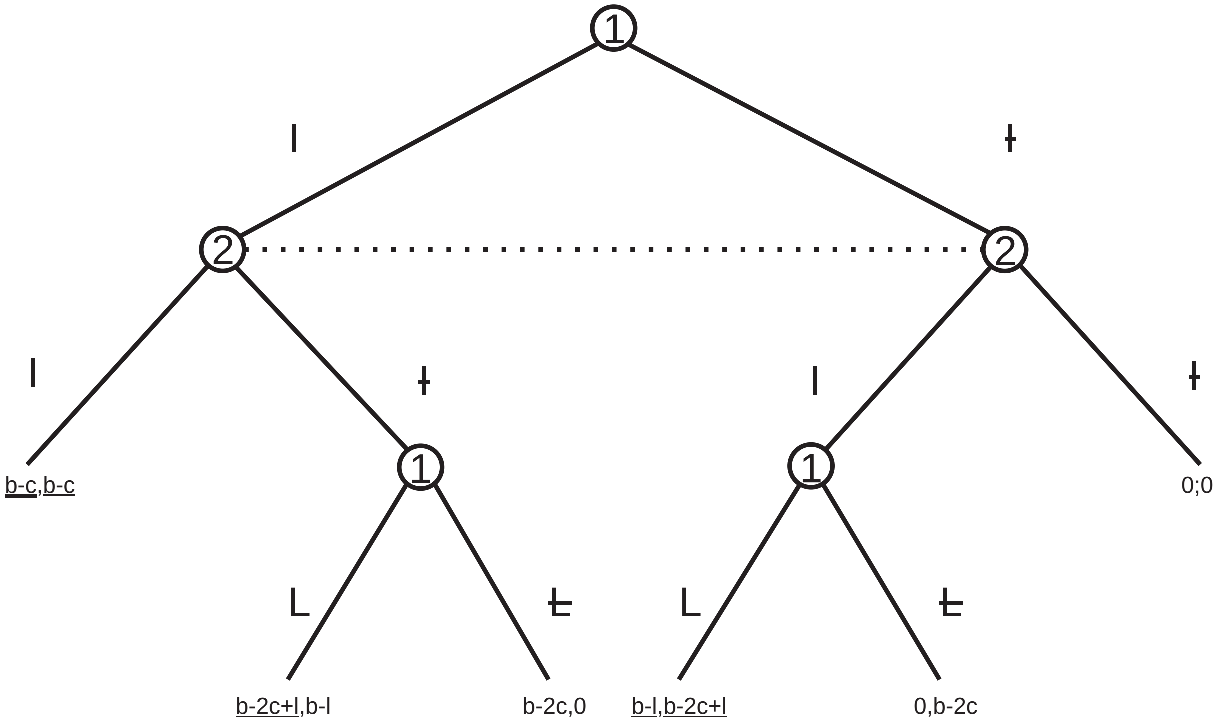

Figure 1
Game Structure with Intellectual Property

By backwards induction, one finds that, at the ultimate node, firm 1 prefers to sell (left branch) or to buy a licence (right branch). Selling a licence is preferable since b-2c+l>b-2c. Buying a licence is preferable since it has been assumed that b-l>0. Given these decisions of firm 1, in both branches, firm 2 prefers to invest. In the left branch, this is due to the fact that it has been assumed that l>c, and consequently b-c>b-l. In the right branch, this is due to the fact that b-2c+l>0, again from the assumptions. Since not investing is dominated for firm 2, at the origin of the game, firm 1 can anticipate firm 2's move. Knowing that firm 2 will always invest, firm 1 compares b-c in the left with b-l in the right branch. Due to the assumption l>c, it prefers to invest.

If the assumptions about the structure of the game and about the payoffs are correct, intellectual property thus indeed dissolves the dilemma. Anticipating that they would be worse off if only the other firm invests and they have to buy a licence, both firms invest from the outset. That way, they attain the individually and socially best outcome.

3. Qualifying the Model of the Innovation Problem

In the baseline model, intellectual property is socially beneficial since the innovation problem is modelled as a prisoner's dilemma. This need not be the case. The game changes if the inventor has a larger individual benefit, or a smaller cost (subsection 3.1); if outsiders have less benefit or more cost (subsection 3.2); and if cooperative invention is more costly (subsection 3.3). All of this is empirically plausible, at least in discernible parts of the economy.

3.1 The Position of the Inventor

In the baseline model, the inventor and outsiders have identical costs and benefits. In entrepreneurial reality, this is often not the case. Firms engage in innovation if they expect a particularly high benefit. Their production is already organised such that the production cost plummets if process innovation is successful. Their customer base is particularly receptive to some product innovation. They dispose of a research and development department that is likely to be successful with little time and effort, meaning that the expected cost of innovation is small.

Within the model, this changes the payoff in case I invest, and the others do not. In the baseline model, this payoff was b-2c. It now becomes b-2c+ε. The game remains a prisoner's dilemma as long as b-2c+ε<0 or ε<2c-b. If ε is in the interval c>ε>2c-b, the preference order for both firms changes to

$$DC > CC > CD > DD$$

This constitutes a battle of the sexes. In ranking notation, it is diagrammed as in Table 4.

	C	D
C	2,2	1,3
D	3,1	0,0

Table 4
Small Additional Benefit for the Inventor

There is still a social problem, but it is reduced to equilibrium selection (cf. Guesnerie 2001). The game has three equilibria. In the two equilibria in pure strategies, one firm invests, and the other does not. The investing firm gets its third-best outcome. The non-investing firm gets its best outcome. The third equilibrium in mixed strategies is symmetric. It asks either firm to invest with probability

$$x = \frac{b - 2c + \varepsilon}{b - c + \varepsilon}$$

In this equilibrium, each firm expects a payoff of

$$xb = b\frac{b - 2c + \varepsilon}{b - c + \varepsilon}$$

At the borderline, i.e. if ε=2c-b, this payoff is 0. Consequently, whenever ε>2c-b, the symmetric payoff is strictly larger than 0, and hence larger than the payoff both expect if they defect. However, mixed strategies are not easy to implement. A practically more relevant solution consists of moving from simultaneous to sequential interaction. By her own move, the first mover determines the equilibrium. In practice, this will often not be difficult to bring about. It suffices if one firm is able to credibly commit to a strategy. However, in this game, the first mover wants to induce the other firm to invest. It must therefore credibly commit to not investing. One option is sinking cost in an advertising campaign for the current product.

The game remains a battle of the sexes if the advantage of the investing firm, compared to the baseline model, is even larger. If $2c>\varepsilon>c$, the preference order changes to

$$DC > CD > CC > DD$$

This constitutes the following game:

	C	D
C	1,1	2,3
D	3,2	0,0

Table 5
Larger Benefit for the Innovator

The two equilibria in pure strategies remain the same. Each firm still prefers the equilibrium in which it does not invest. In the equilibrium in mixed strategies, the probability of investing is still calculated the same way. Inserting the lower bound, i.e. $\varepsilon=c$, into the equation for calculating xb, one finds that the payoff from playing mixed strategies is strictly larger than b-c. In the symmetric equilibrium, the two firms may therefore be sure to be strictly better off than if both of them invest.

Finally, if $\varepsilon>2c$, preferences change to

$$CD > DC > CC > DD$$

This constitutes the following battle of the sexes:

	C	D
C	1,1	3,2
D	2,3	0,0

Table 6
Very Large Benefit for the Innovator

If they play one of the equilibria in pure strategies, now each firm wants to invest. In this case, the shift to a sequential game is even easier to bring about. It suffices for a firm to ostensibly engage in research and development. In this case, the expected payoff in the mixed equilibrium does not admit such a straightforward interpretation. At the borderline, i.e. when $\varepsilon=2c$, the payoff is

$$\frac{b^2}{b+c}$$

This is strictly less than b, i.e. even less than the payoff for the defecting firm. To see this, solve

$$\frac{b^2}{b+c} = b + \eta$$

which gives

$$\eta = -\frac{bc}{b+c}$$

3.2 The Position of Outsiders

In the baseline model, outsiders are able to appropriate foreign innovation at zero cost. In entrepreneurial reality, this is rare (Levin, Klevorick et al. 1987). Normally, imitation comes at a positive cost. Table 7 illustrates the pronounced variance.

Imitation Cost (Divided by Innovation Cost) of 48 New Products, by Industry and Cost of Innovation

Imitation cost (divided by innovation cost)	Innovations costing more than \$1 million: Chemicals	Drugs	Electronics and machinery	Innovations costing less than \$1 million: Chemicals	Drugs	Electronics and machinery
(A) Number of new products						
Less than 0·20	1	1	1	1	0	0
0·20 and under 0·40	0	3	0	0	0	2
0·40 and under 0·60	1	1	2	5	0	0
0·60 and under 0·80	2	5	0	2	0	4
0·80 and under 1·00	2	3	1	2	1	1
1·00 and over	2	2	1	1	0	1
Total	8	15	5	11	1	8
(B) New products weighted by innovation cost* (%)						
Less than 0·20	3	3	17	15	0	0
0·20 and under 0·40	0	11	0	0	0	34
0·40 and under 0·60	‡	1	53	46	0	0
0·60 and under 0·80	44	54	0	13	0	36
0·80 and under 1·00	15	21	9	22	100	18
1·00 and over	38	9	22	4	0	11
Total†	100	100	100	100	100	100

* The weighted number of new products is expressed as a percentage of the column total.
† Because of rounding errors, items may not sum to column total.
‡ Less than 0·5.

Table 7
Imitation Cost
from (Mansfield, Schwartz et al. 1981:908)

This study includes patented innovations. However, in the median, a patent has increased the imitation cost by only 11% (Mansfield, Schwartz et al. 1981:913). The findings from this study are thus also relevant in the situation investigated here, i.e. in the absence of intellectual property rights.

Within the model, positive imitation cost means that, in the DC cell, a firm only expects b-ε. As the study demonstrates, the cost of imitation may even be larger than the cost of invention. In that case, ε>2c. This generates the game in Table 8.

	C	D
C	3,3	1,0
D	0,1	2,2

Table 8
Very High Imitation Cost

The game is a stag hunt. There is again a problem of equilibrium selection. It is solved if the firms can switch to sequential play. Since both firms are best off if both invest, this should not be difficult in practice. It suffices if one firm credibly commits to investing. Since both equilibria in pure strategies are symmetric, the third equilibrium in mixed strategies is of lesser interest. It asks both firms to invest with probability

$$x = \frac{2c - b}{c + \varepsilon - b}$$

At the borderline, i.e. with ε=2c, this gives each firm a payoff of

$$\frac{(b-2c)^2}{b-3c}$$

Since already b-2c<0, the denominator, and hence the term, are negative—and the larger ε, the more negative they are. In the mixed equilibrium, the firms thus have strictly less than in the worse of the equilibria in pure strategies.

In the next interval, imitation is less costly than invention. But the cost of imitation still is above the benefit. In this interval, 2c>ε>b. This makes for preferences

CC > DD > DC > CD

The resulting game still is a stag hunt.

	C	D
C	3,3	0,1
D	1,0	2,2

Table 9
Imitation Cost Above Benefit

The two equilibria in pure strategies are the same as before. In the mixed equilibrium, at the upper bound, i.e. with ε=b, both firms expect a payoff of 0. Since, in this interval, ε is strictly larger than b, the payoff is always negative. In the mixed equilibrium, the firms thus still expect strictly less than in the worse of the two equilibria in pure strategies.

In the third interval, the cost of imitation is smaller than the benefit, but larger than the cost of cooperative invention. In this interval, b>ε>c. This changes the ranking of outcomes to

CC > DC > DD > CD

and generates the following game:

	C	D
C	3,3	2,0
D	0,2	1,1

Table 10
Imitation Cost above Cost of Cooperative Invention

This game has a single equilibrium in pure strategies. In this equilibrium, both firms invest right from the beginning.

The strategic implications are the same if imitation is less beneficial than invention. Formally, it does not matter whether –ε results from the fact that imitation has a cost, or that it yields a smaller benefit. Empirically, the effect is plausible since imitation typically takes time. Table 11 shows the effect, and its variance.

Imitation Time (Divided by Innovation Time) of 48 New Products, by Industry and Cost of Innovation

Imitation time (divided by innovation time)	Innovations costing more than $1 million			Innovations costing less than $1 million		
	Chemicals	Drugs	Electronics and machinery	Chemicals	Drugs	Electronics and machinery
(A) Number of new products						
Less than 0·30	1	2	1	2	0	0
0·30 and under 0·50	1	5	1	2	0	2
0·50 and under 0·70	1	3	1	4	1	2
0·70 and under 0·90	3	0	0	1	0	1
0·90 and under 1·10	1	3	1	1	0	1
1·10 and over	1	2	1	1	0	2
Total	8	15	5	11	1	8
(B) New products weighted by innovation cost* (%)						
Less than 0·30	3	10	35	16	0	0
0·30 and under 0·50	2	28	17	36	0	16
0·50 and under 0·70	35	24	19	27	100	23
0·70 and under 0·90	22	0	0	16	0	14
0·90 and under 1·10	18	16	22	4	0	18
1·10 and over	19	23	9	2	0	30
Total†	100	100	100	100	100	100

* The weighted number of new products is expressed as a percentage of the column total.
† Because of rounding errors, items may not sum to column total.

Table 11
Imitation Time
from (Mansfield, Schwartz et al. 1981:909)

In the meantime, the successor makes no additional profit. Often, she even incurs a loss. It is most pronounced if the innovation reduces the cost for producing a homogenous product, if marginal cost is constant and if the capacity of the innovator is not limited. In that case, the innovator will reduce her price slightly below the production cost of the incumbent. This will reduce demand for the incumbent's product to zero. Until the incumbent catches up, she makes zero profit. If there is a fixed cost, she incurs a loss (Bertrand 1883; Kreps and Scheinkman 1983).

3.3 The Cost of Cooperative Invention

Finally, the cost of cooperative invention will often be above the cost of individual invention. This may be due to economies of scale and scope, learning effects or x-inefficiencies, to list only the most important factors. Within the model, this means that the payoff in the CC cell goes down to b-c-ε. This has no effect on the equilibrium as long as the cost of cooperative invention is smaller than the individual benefit, i.e. as long as b-c-ε>0 or ε<b-c. In the next interval, the cost of cooperative invention is above benefit, but below the cost of individual invention. In this interval, c>ε>b-c. This changes preferences to

DC > DD > CC > CD

and generates the following game:

	C	D
C	1,1	0,<u>3</u>
D	<u>3</u>,0	<u>2</u>,<u>2</u>

Table 12
Cooperative Invention Prohibitively Costly

The equilibrium is the same as in the original prisoner's dilemma. Neither firm invests. However, this is no longer a dilemma. Both firms would be worse off investing, even if the other firm also did.

The structure of the game, and the equilibrium, remain the same if the cost of cooperative invention is even higher, i.e. if ε>c. In that case, preferences are

DC > DD > CD > CC

which makes for the following game:

	C	D
C	0,0	1,<u>3</u>
D	<u>3</u>,1	<u>2</u>,<u>2</u>

Table 13
Cooperative Invention More Costly Than Individual Invention

4. Qualifying the Effect of Intellectual Property

The previous section has shown that there are manifold, empirically plausible situations where the interaction between several firms interested in an innovation is not well captured by a prisoner's dilemma. But even if the prisoner's dilemma is an appropriate model of the innovation problem, intellectual property is not always the desirable solution. Many plausible changes to the model do, however, not change the equilibrium. Provided there is a prisoner's dilemma, intellectual property thus is a fairly robust institution. There are, however, a number of empirically relevant changes that make intellectual property a problematic intervention.

Three situations are worth investigating. In reality, licensees often suffer a bigger disadvantage (subsection 4.1). Even if cooperative invention has not been so detrimental as to change the original problem, its drawbacks can still have an undesirable impact on the effects of intellectual property (subsection 4.2). Finally, in commercial practice, intellectual property often only grants partial protection. It makes imitation more costly, but not impossible (subsection 4.3).

4.1 Drawbacks for Licensees

In the baseline model, the benefit from invention is the same for both firms. In practice, this is often not true. The inventor only grants licences after she has built a stable customer base. The licence comes with terms and conditions that make it impossible to exploit the full benefits from the invention. Within the model, this means that the payoff for ƗIL decreases to b-l-ε. As will be shown, this changes the reasoning quite profoundly. But in equilibrium, both firms still invest right from the beginning. With this change, the game tree can be modelled as in Figure 2.

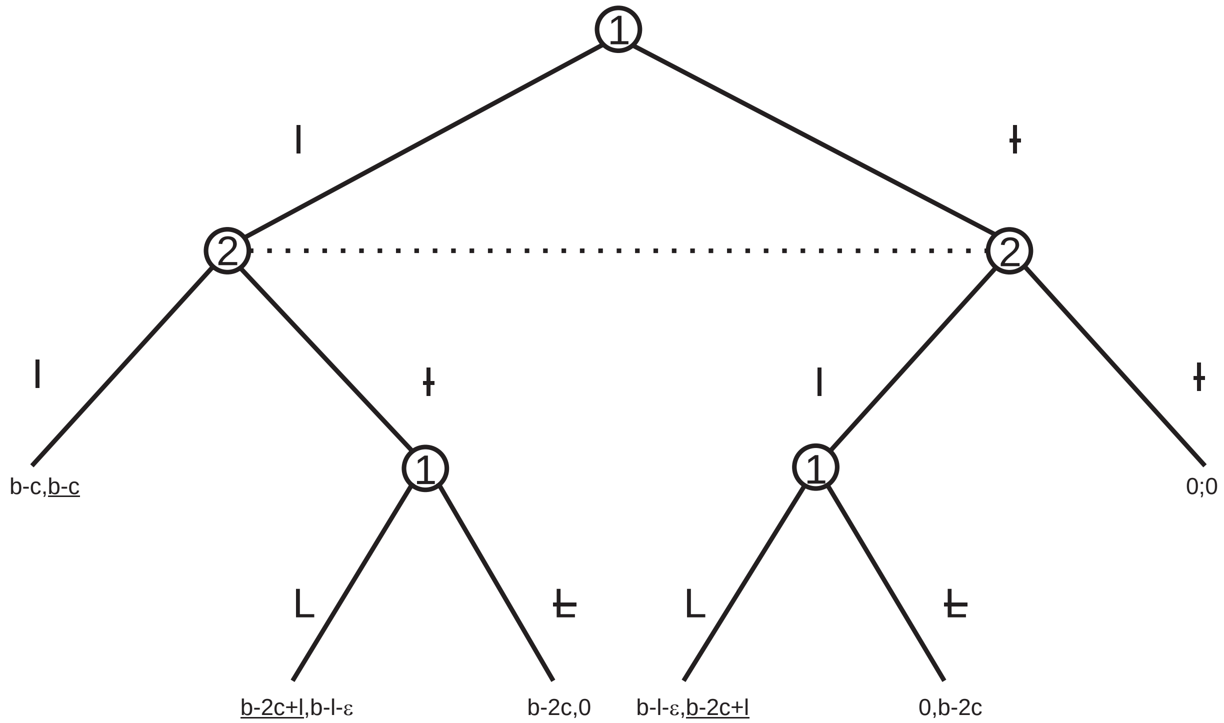

Figure 2
Drawbacks for Licensees

The equilibrium and the reasoning remain the same as long as b-l-ε>0 or ε<b-l. If ε>b-l, in the last node of the right branch, firm 1 no longer wants to buy a licence. Consequently, since b-2c<0, in the right branch, firm 2 no longer wants to invest. To find the equilibrium, the game is best represented in normal form.

	I	Ɨ
IL	b-c,b-c	b-2c+l,b-l-ε
IȽ	b-c,b-c	b-2c,0
~~ƗL~~	~~b-l-ε,b-2c+l~~	~~0,0~~
~~ƗȽ~~	~~0,b-2c~~	~~0,0~~

Table 14
Drawbacks for Licensees, Normal Form

The solution is found by iterated dominance. IL dominates IȽ, since b-c>0 and b-2c+l>0. IL dominates ƗL even more, since b-l-ε<0. In the remaining cells, I dominates Ɨ, since b-c>0>b-l-ε. In the only equilibrium, both firms invest.

4.2 Disadvantages of Cooperative Invention

As has been shown above, the problem does not change as long as cooperative invention is only mildly more costly, or less advantageous, than in the baseline model. It remains a prisoner's dilemma as long as b-c-ε>0. However, the effect of intellectual property becomes uncertain as soon as ε>l-c. In the interval b-c>ε>l-c, the game can be represented as follows:

	I	Ɨ
IL	b-c-ε,b-c-ε	<u>b-2c+l,b-l</u>
~~IŁ~~	~~b-c-ε,b-c-ε~~	~~b-2c,0~~
ƗL	<u>b-l,b-2c+l</u>	0,0
~~ƗŁ~~	~~0,b-2c~~	~~0,0~~

Table 15
Costly Cooperative Invention in the Prisoner's Dilemma

Domination reduces the game. ƗŁ is dominated by IL, since b-c-ε>0 and b-2c+l>0. IŁ is (weakly) dominated by IL, since b-2c+l>b-2c. The remaining game is a battle of the sexes. If firm 1 plays IL, firm 2 prefers Ɨ, since b-l>b-c-ε implies ε>l-c, as assumed. If firm 1 plays IŁ, firm 2 prefers I, since b-2c+l>0. Likewise, firm 1 prefers ƗL if firm 2 plays I, since b-l>b-c-ε. And firm 1 prefers IL if firm 2 plays Ɨ, since b-2c+l>0.

Despite legal intervention the game thus has multiple equilibria. In the two equilibria in pure strategies, one of the firms invests. The other buys a licence. The investing firm makes a larger profit. The legal intervention thus creates an incentive to preempt foreign investment. The winner may invest the difference between both payoffs, minus a marginal amount η, and still make a positive profit. Formally, she may at most invest b-2c+l-(b-l)-η=2l-2c-η. Note that this is not a patent race,[5] but a race to credibly commit to an investment strategy.

The third equilibrium in mixed strategies asks both firms to invest with probability

$$x = \frac{b - 2c + l}{b - c + \varepsilon}$$

If they do, both expect

$$(b - l)\frac{b - 2c + l}{b - c + \varepsilon}$$

Evaluating this at the lower bound, i.e. at ε=l-c, yields b-l. If they play the mixed equilibrium, each party may therefore be sure to make a higher profit than in the more disfavourable of the two equilibria in pure strategies. Moreover, in the mixed equilibrium, payoffs are the same for both firms. The mixed equilibrium is therefore more equitable. It is, however, difficult to bring about in competitive practice.

5 On patent races, see below, Section 5.

4.3 Patents as Attenuated Property Rights

Imitation not only matters for the definition of the innovation problem. It also changes the effects of intellectual property rights, once they are introduced. Typically, patents do not make imitation impossible, but only more expensive (Mansfield, Schwartz et al. 1981; Lemley and Shapiro 2005). Table 16 shows how small the influence of patents on imitation cost typically is.

Table 8. Cost of Duplicating an Innovation as a Percentage of Innovator's R&D Cost, Frequency Distribution of Median Responses

Type of innovation	*Less than 25 percent*	*26 to 50 percent*	*51 to 75 percent*	*76 to 100 percent*	*More than 100 percent*	*Timely duplication not possible*
New process						
Major patented new process	1	5	19	66	26	10
Major unpatented new process	5	10	55	49	6	2
Typical patented new process	2	15	61	41	6	2
Typical unpatented new process	8	43	58	14	4	0
New product						
Major patented new product	1	4	17	63	30	12
Major unpatented new product	5	13	58	40	7	4
Typical patented new product	2	18	64	32	9	2
Typical unpatented new product	9	58	40	15	5	0

Source: Survey of 127 lines of business.

Table 16
Impact of Patent on Imitation Cost
from (Levin, Klevorick et al. 1987:809)

Patents are therefore fairly attenuated property rights (Eggertsson 1990).

Within the model, this means that the benefit of outsiders who have not bought a licence is $\varepsilon > 0$. This makes for the game represented in Table 17. It has an equilibrium different from the baseline game, provided $\varepsilon > b - c$.

	I	I̶
IL	b-c,<u>b-c</u>	<u>b-2c+l</u>,b-l
~~IL̶~~	~~b-c,b-c~~	~~b-2c,ε~~
~~I̶L~~	~~b-l,b-2c+l~~	~~0,0~~
I̶L̶	<u>ε</u>,b-2c	0,<u>0</u>

Table 17
Attenuated Property Rights

Domination simplifies the game. IL dominates I̶L, since b-c>b-l, and b-2c+l>0, both on the basis of the original assumptions. IL also (weakly) dominates IL̶, since b-2c+l>b-2c. The remaining game has no equilibrium in pure strategies. If firm 1 plays IL, firm 2 prefers I, since l>c. If firm 1 plays I̶L̶, firm 2 prefers I̶, since 0>b-2c. If firm 2 plays I, firm 1 prefers I̶L̶, since ε>b-c. And if firm 2 plays I̶, firm 1 prefers IL, since b-2c+l>0.

In the mixed equilibrium, firm 1 invests with probability

$$x = \frac{2c - b}{c + l - b}$$

and firm 2 invests with probability

$$y = \frac{b - 2c + l}{l + \varepsilon - c}$$

If they do, firm 1 expects

$$\varepsilon \frac{b - 2c + l}{l + \varepsilon - c}$$

At the borderline, i.e. if ε=b-c, this simplifies to b-c. Consequently, firm 1 expects somewhat more than if both firms cooperate from the beginning. Firm 2 expects

$$(b - l)\frac{2c - b}{c + l - b}$$

Note that firm 2's payoff does not depend on ε. It is positive, since all three terms are >0. But it is strictly smaller than firm 1's payoff. To see this, solve the following equation for θ, the difference between the two payoffs at the lowest possible value of ε:

$$(b - l)\frac{2c - b}{c + l - b} = b - c + \theta$$

This yields

$$\theta = -\frac{cl - c^2}{c - b + l}$$

This is bound to be negative. The numerator is positive, since l>c. The denominator is positive, since c+l>b. Consequently θ<0.

This is a terse environment for innovation. It is highly likely that the firms will miss the equilibrium altogether. A mixed equilibrium is difficult to implement anyhow. The problem is aggravated here, since both firms must choose different probabilities, and since either firm must believe the other to exactly play the equilibrium probabilities. More importantly even, the firms do not expect the same payoffs. Now in reality, the roles of firm 1 and firm 2 are not predefined. Therefore a race to be firm 1 should take place. Such a race is, however, more difficult to manage than when cooperative invention is more costly. Here, the firm would have to credibly commit to investing, with a well defined probability. The situation is much more likely to end in chaos.

5. Robustness

How robust is the argument thus developed? Two changes to the baseline model are worth considering. One may explicitly introduce the demand side (subsection 5.1), and one may allow for a patent race (subsection 5.2).

5.1 Introducing the Demand Side into the Baseline Model

In the baseline model, the demand side of the market is represented indirectly. Competition prevents buyers from paying excessive prices, and competition ensures that buyers get the products that are closest to their preferences. For most industries, the indirect representation does not omit important elements of the problem. Of course, buyers must have a positive willingness to pay. Otherwise producers would not have an incentive to engage in innovation. However in most industries, even absent intellectual property, buyers stand no chance of appropriating the idea. For them, the idea as such is useless. They lack the ability to transform the idea into a product.

Occasionally, this is different. Electronic documents and computer programmes are the most important exceptions. Everybody can copy them at almost no cost and effort. Another case in point is demand by downstream industries. They sometimes have enough know-how and resources to manufacture semifinished parts themselves once they have seen the idea. In principle, neither of these calls for a different model. As long as coalitions are excluded, the two-person model also captures interaction in large populations. However the larger the population, the more difficult cooperative invention is to manage. In such settings, intellectual property may be justified as a tool for reducing transaction costs.

A radically different modelling strategy would only look at the interaction between one producer and a community of potential buyers. Such a model would thus ignore competition between producers. In order to be meaningful, it must assume that buyers possess the ability to appropriate the idea. This leads to a less informative model. Since there is no other potential inventor, for the single producer, defection does not make sense. Nor is it possible for a buyer to contribute in any other way than by buying the product. For buyers there is thus no meaningful CD option. It collapses with the DD option. The benefit the single producer can expect from selling the product must suffice to cover the cost of innovation. $b-c>0$ must therefore hold. The benefit for producers is the aggregate payment of buyers. The consumer rent is denoted as r. This makes for the following payoffs and hence preferences:

	benefit	cost	payoff	rank
DC	0	0	0	1
CC	b	-c	b-c	2
DD	0	0	0	1
CD	0	-c	-c	0

Table 18
Single Producer's Preferences

	benefit	cost	payoff	rank
DC	b+r	0	b+r	2
CC	b+r	-b	r	1
DD	0	0	0	0
CD	0	-c	0	0

Table 19
Buyers' Preferences

This constitutes the following game:

		buyers	
		C	D
seller	C	2,1	0,2
	D	1,0	1,0

Table 20
Game between Buyers and a Single Seller

This is still a dilemma. Without legal intervention, the seller will not invest; buyers will not contribute to the cost of invention. Both would be better off if the seller invested and the buyers paid. Consequently, in the alternative modelling strategy, the model loses richness, but the strategic implications remain the same.

5.2 Patent Races

In the baseline model, there are races for invention. But these races result from attempts to force the competitor into a less favourable equilibrium, not from the exclusive character of patent protection. Actually, patent races are excluded from the baseline model by the assumption that licences are only bought by firms that have not invested. Since patent races are frequent in practice, and are a popular topic in theory (Loury 1979; Lee and Wilde 1980; Reinganum 1981; Harris and Vickers 1985), it is worth extending the model. In extensive form, the extended model looks like this:

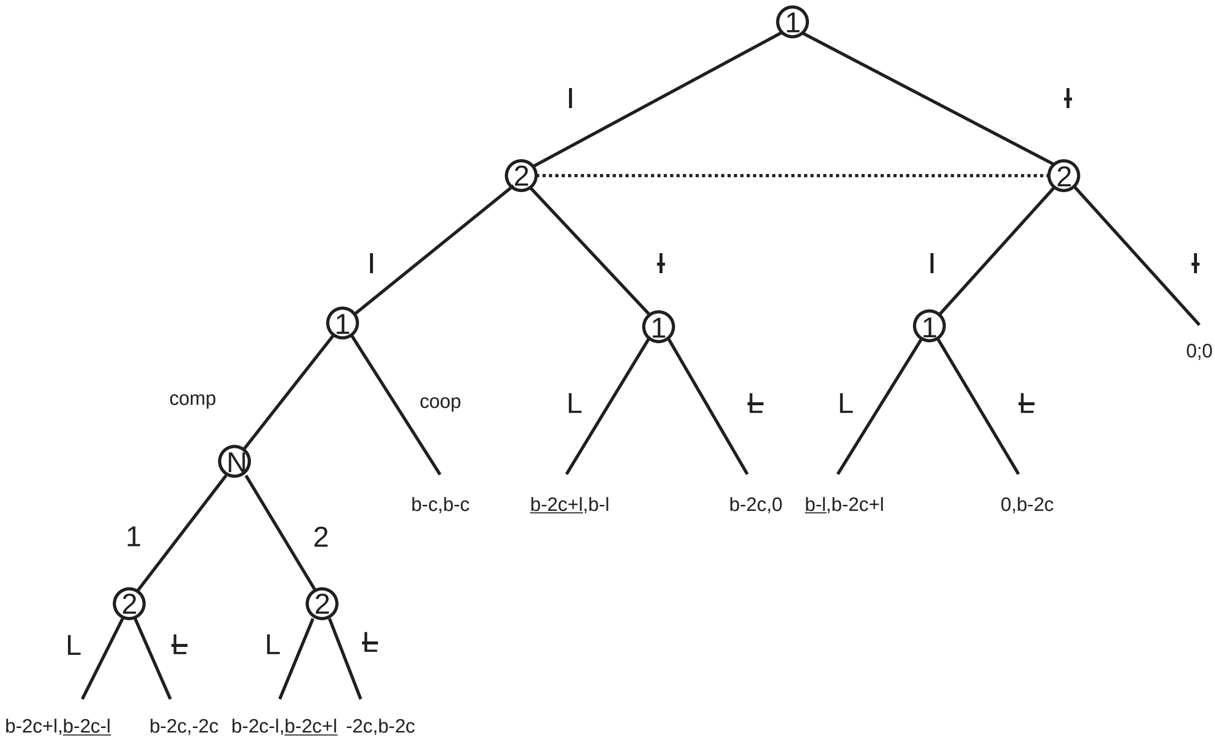

Figure 3
Patent Race

The extension is in the outer left branch. If both firms have decided to invest, firm 1 may choose between cooperative and competitive innovation. If firm 1 opts for competition, Nature decides which of the two firms is first successful, and hence protected by the patent. In the last node, firm 2 chooses between buying or selling a licence, on the one hand, and not trading a licence, on the other hand. In all four cases, both firms have invested, which is why payoffs are always reduced by -2c.

The game is solved by backwards induction. If firm 2 has been successful, she prefers selling a licence, since b-2c+l>b-2c. Firm 2 also prefers to buy a licence if she has lost the patent race. For b-2c-l>-2c, or b-l>0, on the basis of the original assumptions. Note that, in this case, firm 2 chooses between two negative payoffs. Firm 1’s choice between competition and cooperation depends on Nature's move. Firm 1 competes if

$$z(b-2c+l)+(1-z)(b-2c-l)>b-c$$

where z is the probability that firm 1 will win the patent race. Solving for z, one finds the minimum probability of success to be

$$z \geq \frac{c+l}{2l}$$

In reality, it is quite likely that both firms will not estimate their individual probability of success the same way. Overoptimism is a fairly robust phenomenon (see only van den Steen 2004). As a result, the firms will engage in a patent race although, in the fully informed equilibrium, they would cooperate. In the following, this additional complication is assumed away. It thus is assumed that both firms believe in the same value of z, and that they believe that the other believes that they believe this.

If they both believe that z is above the critical value, firm 1 expects b-c+η, where η is a markup. Consequently, in the outer left branch, firm 1 competes. In the left branch, firm 2 therefore invests if

$$z(b-2c-l)+(1-z)(b-2c+l)>b-l$$

Inserting the threshold value of z, the left-hand side becomes b-3c, which is strictly less than the right-hand side. Consequently, in the left branch, firm 2 does not invest. However, for the same reasons as in the baseline model, in the right branch, firm 2 invests. To find the equilibrium, the game is best represented in normal form.

	IL	I~~L~~	~~I~~L	~~IL~~
ICompL	b-c+η,b-3c-η	b/2l(c+l)-2c+η, b-2c-b/2l(c+l)-η	b-2c+l,b-l	b-2c+l,b-l
IComp~~L~~	b-c+η,b-3c-η	b/2l(c+l)-2c+η, b-2c-b/2l(c+l)-η	b-2c,0	b-2c,0
ICoopL	b-c,b-c	b-c,b-c	b-2c+l,b-l	b-2c+l,b-l
ICoop~~L~~	b-c,b-c	b-c,b-c	b-2c,0	b-2c,0
~~I~~L	b-l,b-2c+l	b-l,b-2c+l	0,0	0,0
~~IL~~	0,b-2c	0,b-2c	0,0	0,0

Table 21
Patent Race, Normal Form

In this matrix, "Comp" means that firm 1 engages in a patent race, while "Coop" means that it does not. Note that L and ~~L~~ mean different things to the two players. In the rows, these two letters stand for firm 1's decision in the third node of the game. In the columns, the two letters stand for firm 2's choice in the last node of the left branch.

The game is solved by iterated dominance. ICoopL dominates ~~IL~~. b-c>0 and b-2c+l>0, both on the basis of the assumptions of the baseline game. ICoopL also dominates ~~I~~L. b-c>b-l, or l>0, and again b-2c+l>0. ICoopL further (weakly) dominates ICoop~~L~~. b-2c+l>b-2c, or l>0. ICompL (weakly) dominates IComp~~L~~, again since b-2c+l>b-2c. In the remaining game, for player 2, IL (weakly) dominates I~~L~~. To see this, solve

$$b-3c-\eta+\theta=b-2c-\frac{b}{2l}(c+l)-\eta$$

for θ, which yields

$$\theta=c-\frac{b}{2l}(c+l)$$

If $\theta<0$, this means that I~~L~~ is dominated. θ is negative if the second term is larger than c. On the basis of the assumptions of the baseline game, l>c. Consequently, the second term is larger than $\frac{b}{l}c$. This is bound to be larger than c, given b>l. Consequently, $\theta<0$ holds.

In the remaining game, ICompL (weakly) dominates ICoopL, since b+c+η>b+c. Finally, ~~I~~L and ~~IL~~ (which are identical when coupled with ICompL) dominate IL, since b-l>b-3c-η. This determines the equilibrium. It depends on the value of z, i.e. on the degree of asymmetry between the firms. If the asymmetry is pronounced, i.e. if

$$z \geq \frac{c+l}{2l}$$

the firm that is more likely to be successful invests. The other buys a licence (this coincides with the result of Harris and Vickers 1985). If the asymmetry is less pronounced, both firms innovate cooperatively. In neither case is there an actual patent race.

6. Conclusions

Is intellectual property a necessary condition for innovation? It depends. In many plausible situations, there is no dilemma in the first place, calling for legal intervention. In many of these situations, there is at most a problem of equilibrium selection. In some, there is no social problem at all. Empirical research on innovation across industries makes it likely that policymakers will be able to discern many of these situations (Mansfield 1986; Burk and Lemley 2003; Federal Trade Commission 2003:chapter 3), allowing them to design industry-specific rules.

Moreover, intellectual property frequently is problematic even if the underlying problem is indeed a (prisoner's) dilemma. The legal intervention may trigger a wasteful race to be the first, or the last, to innovate, as the case may be. In a significant number of cases, the participating firms would have to randomise between investing and not investing, with well-defined probabilities. This is hard to implement in entrepreneurial practice. In equilibrium, frequently all of the parties have to invent cooperatively. This is difficult to do, and becomes increasingly so, the larger the number of those competing. For all of these reasons, policymakers are well advised to take alternative institutional arrangements seriously, like open-source invention.

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