IPR and North-South Hold-up Problem in Sequential R&D[1]

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Abstract

This paper develops a model of North-South bargaining in a sequential R&D framework to shed light into the mechanism by which underinvestment in maintaining genetic diversity and inefficient flow of information in bioprospecting occurs. We show that when property rights in genetic resources conferred in the South are not enforceable *ex ante* across jurisdictions (in the North), a hold-up problem may arise and lead to underinvestment. We highlight the role that legal institutions may play in shaping the incentives to invest. Under some specific conditions and legal remedies, *ex post* enforcement of property rights across jurisdictions helps circumvent the hold up problem and encourages socially optimal investments. However, these conditions are not general.

1 Introduction

In 1995, a coalition of NGOs challenged the patent awarded by the US Patent Office to the agro-chemical company, W.R. Grace & Co for its method of stabilising azadirachtin[1] in solution and the stabilised solution itself. The challengers invoked the lack of novelty of the invention on the basis that it was simply an extension of the traditional processes used for millennia for making neem-based products in India. (Shiva, 1996) However, the US Patent Office held that the patent was valid under US legislation. Another patent held by W.R. Grace for a method for controlling fungi on plants also derived from the neem tree was later challenged by a legal opposition, this time in the European Patent Office (EPO). The EPO eventually revoked that patent on the fungicidal product due to its lack of novelty and "inventive step". (Bullard, 2005)

These two cases are illustrative of the inability of the North—which is reliant on biodiversity located in the South—and the South to find a common ground to address the issue of ownership of informational goods such as genetic resources. Yet, the coordination of each region's legal system to enforce rights in information-based genetic resources can potentially generate efficient investment in R&D for health services. The lack of coordination results from a deeply asymmetric situation where North—technology rich and biodiversity poor—and South—gene rich but technology poor—assign property rights over informational goods according to their respective comparative advantage. The North promotes an intellectual property system that protects technology-based knowledge and invention at the expense of the discovery of naturally occurring products. In contrast, the South promotes an intellectual property system that protects and rewards the discovery of useful information contained in natural products through a process of observation, experimentation, and environmental stewardship.

The difficulty in reconciling these two systems results in little or no recognition by the North of the South's property rights in genetic information. This situation creates an inherent uncertainty about the enforcement of these rights in the North. In particular, given the sequential nature of R&D in the life sciences industry (agriculture and pharmaceuticals), this absence of coordination may result in underinvestment as predicted by Green and Scotchmer (1995) if the first innovator—here the South—is inadequately compensated for the information supplied to the second innovator. What are the consequences of the uncertainty about the protection of property rights upon investment in preserving genetic diversity, access to genetic resources and drug R&D? What is the role of legal institutions in shaping the incentive to invest? Can an *ex post* remedy yield efficiency given *ex ante* uncertainty of enforcing the South's property rights?

Following Swanson and Goeschl (2000), we suppose that North-South bilateral relationship takes

[1] Azadirachtin is the active chemical compound contained in the neem tree found in India

place within a non-integrated vertical industry where the South provides necessary intermediate goods (genetic resources) to the North which subsequently use them as inputs to develop patentable pharmaceuticals. We develop a model of North-South bargaining in a sequential R&D framework to analyse how the problem of rent appropriation impacts the South's investment in preserving genetic diversity and the flow of information generated within this vertical industry. We shed light on the mechanism by which underinvestment in maintaining genetic diversity and inefficient flow of information in bioprospecting occurs. We show that even with the creation of a property right protecting genetic resources, uncertainty *ex ante* about the enforceability of the assigned right across jurisdictions may lead to a hold-up problem—underinvestment in environmental stewardship. As we will see, the bargaining process is subject to renegotiation once uncertainty is resolved by courts' ruling. This renegotiation is likely to dissipate investment returns and prevents the investor from appropriating the full marginal benefit of his investment while bearing all the costs. We also highlight the role that legal institutions play in shaping the incentive to invest. Under some specific conditions and legal remedies, we show that *ex post* the enforcement of property rights across jurisdictions helps circumvent the hold up problem and encourages socially optimal investments. But these conditions are not general.

Section 2 presents stylised facts about the North-South bilateral relationship in the framework of sequential investment. We then layout the model and discuss the results in Section 3. Section 4 concludes the chapter.

2 North–South relationship in Sequential R&D: Stylised facts

Agents. North (N) and South (S) refer to two distinct regions comprised of: (i) distinct consumer groups CG_N and CG_S; (ii) distinct firms F_N and F_S; and (iii) distinct legal institutions or courts Ct_N and Ct_S. The two regions could realise joint benefits by cooperating in the production of R&D for health services, but must coordinate their individual legal systems to generate these incentives toward cooperation. There are four crucial dimensions within which North and South interact.

Separate R&D Contributions. Firms from the North and the South, F_N and F_S, can cooperate for mutual benefit through coordination in the supply of inputs within a process of sequential R&D. If they cooperate successfully, then a higher quality of health services is available to consumers. The South is gene rich and technology poor. The firms in the South F_S are specialised in the provision of genetic material g and the maintenance of genetic diversity through investment in land use L. The North is technology rich and biodiversity poor. The firms in the North F_N use information contained in the genetic resources g and combine them with technology in the North to search for new leads and develop new drugs d.

Separate Markets. North and South have distinct consumer groups CG_N and CG_S, and therefore separate markets for medicinal products. Consumers in the South CG_S have low income and a low willingness to pay for medicines. By contrast, consumers in the North CG_N have high income and are willing to pay high prices for drugs developed by the pharmaceutical industry.

Separate Property Rights Systems. In each region, there exists a property rights system that attempts to generate incentives for innovation by ensuring appropriation of the returns on investments in that region. Property rights in Land L and genetic resources g are conferred to F_S in the South. Likewise, the drug d developed by F_N in the North has a property right declared in it. Property rights conferred by a given region exist automatically only within that region's boundaries, and must be adopted and implemented by the other region to be given effect there.

Separate Court Systems. Court systems exist in each region for enforcement of property rights. There is *ex ante* uncertainty about whether any right conferred in a given jurisdiction—say the right in the genetic resources—will be recognised and enforced by courts in the other region. It is possible for courts to either recognise the property rights declared in the other region and thus enforce them domestically, or to not recognise them at all. Both the Northern and Southern courts, Ct_N and Ct_S, recognise F_S's property right in land L. The property right in g is recognised in the South by Ct_S, i.e. the jurisdiction in which it has been conferred. Similarly, the property right in d is recognised by Ct_N.

Table 1: Stylised Facts on North/South Interactions with Land Use Investment

	South	North
Vertical Industry	• F_S: Upstream	• F_N: Downstream
Separate R&D Contributions	• Biodiversity Rich (Land L and Genetic Resources g) • Technology Poor: no d	• Biodiversity Poor: no L and g • Technology Rich: produces drugs d
Separate Markets	• Low income: CG_S have low willingness to pay • Medicinal plants • F_S serves only CG_S	• High income: CG_N have high willingness to pay • Pharmaceuticals • F_N serves only CG_N
Separate Property Rights Systems	• F_S has property rights in L and g	• F_N has a property right in d
Separate Courts Systems	• Ct_S enforces rights in g	• Ct_N enforces right in d. *Ex ante* enforcement of right in g with probability ξ
	Both courts Ct_S and Ct_N recognise F_S's property right in land L	

3 Sequential R&D and the Hold-up Problem

3.1 Background

Consider two risk-neutral agents F_N (he) representative of the firms from the North and F_S (she) representative of the firms from the South. F_S owns some genetic material g useful in producing medicines that treat conditions both in the North and the South. F_N produces drugs d using g an input.

Governments in these two regions aim at advancing social welfare by maximising both producers' and consumers' surplus. The challenge faced by each government domestically, is to create the proper incentive for firms F_N and F_S to invest in R&D for health services: investment in land use L for the conservation of genetic diversity by F_S, which allows the collection of natural compounds g necessary to produce herbal medicines; and investment in pharmaceutical drug development by F_N. This challenge is addressed in each region by conferral of property rights. The South grants F_S exclusive rights in genetic resources g and L, while the North grants F_N exclusive rights in drug d. These statutory rights are enforced within each region by domestic courts Ct_N and Ct_S.

We assume that there is no coordination between the two regions to harmonise their separate property rights systems. As a result, there is no *ex ante* enforceability of the property rights across jurisdictions. In the absence of *ex ante* enforceability, there is an inherent uncertainty about the state of the world. This uncertainty is captured by the probability $\xi \in [0,1]$ representing the *ex ante* common belief that the right will be enforced.

This paper will focus on F_S's incentives to invest in L and to trade the genetic resources g needed by F_N as inputs for drug development. For this reason, we focus on the producers' surplus as a social welfare criterion.

We now model North/South interaction as a bargaining game to investigate the implications of the lack of coordination of the property rights systems on North/South cooperation to invest in R&D in the life sciences sector. In particular, we will examine how the incentive to maintain biodiversity and exchange genetic resources in the South, and the incentive to develop new drugs based on natural inputs in the North, are affected.

3.2 Bargaining process

F_N wishes to sign an agreement with F_S to be granted access to g in return for a transfer payment T, in order to search for new leads. If an agreement is reached, F_S will earn $U = u(g, L) + T - c(g) - c(L)$ and F_N will receive $V = v(g, d) - T - c(d)$, where the benefits u and v are strictly increasing and concave in their arguments and their cross derivatives are positive; $c(g)$ is the cost of supply of g and $c(L)$ is the investment cost in land use L incurred by F_S; $c(d)$ is the cost of drug development to F_N. All cost functions are increasing and convex in their arguments. We also assume that investment in L is observable by F_S and F_N but not verifiable by a third party—the court in the North Ct_N—so that L cannot be contracted. For example, we may think that investment in time and resources for environmental stewardship cannot be observed by Ct_N.

If F_S rejects the offer and denies F_N access to the genetic resources, F_N may nevertheless be tempted to invest in drug development, using g without F_S's consent. This temptation exists because of the absence of *ex ante* enforceability. If F_N decides to invest in d then F_S will file a legal case for infringement of her right in the Northern court. Once the court's ruling has resolved the uncertainty, the two parties are free to renegotiate if there are gains from trade. Given the absence of *ex ante* enforceability, renegotiation is likely to cause the classical hold-up problem much talked about in the literature. (Klein et al., 1978; Williamson, 1979; and Grossman and Hart, 1986)

The sequence of decisions and payoffs is described as follows:

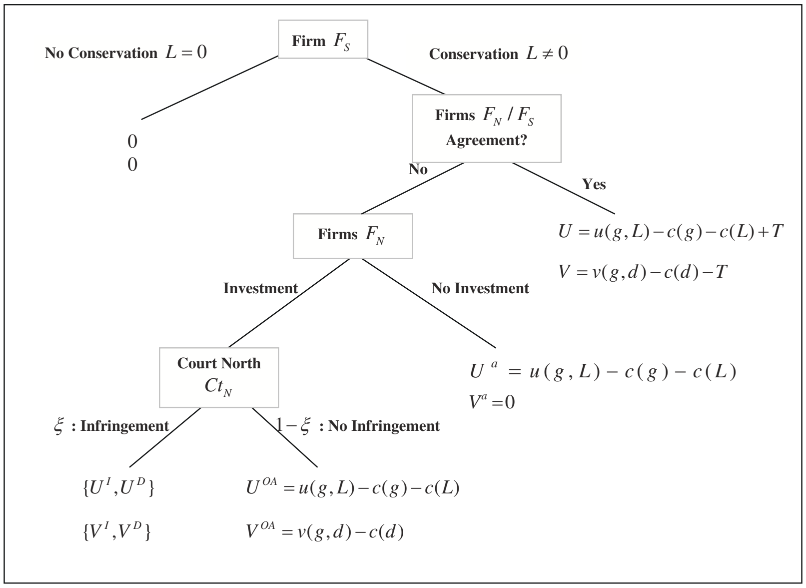

Figure 1: Decision Tree: North/South Hold-up Problem

At time t_0: F_S decides whether or not to invest in conservation L to maintain a flow of genetic resources g.

At time t_1: F_N makes an offer to F_S to be granted access to the genetic resources g against a transfer payment. If the contract is accepted then we consider it will be enforced.

At time t_2: If F_S rejects the offer and denies F_N access to g, then F_N must decide whether to use g without F_S's consent and develop a drug.

At time t_3: If F_N opts for drug development d then F_S files a case in the Northern court Ct_N.

At time t_4: Ct_N makes a ruling.

At time t_5: F_N and F_S are free to renegotiate *ex post* after the court's ruling.

3.3 Benchmark outcomes

Efficient Outcome Assume that the governments in both regions decide to coordinate their legal systems by mutually recognising the property rights granted in both regions. Then there is no more uncertainty about *ex ante* enforceability of the rights across borders. Under this backdrop, if the two firms F_N and F_S agree to cooperate, then they will choose g, d and L to maximise the joint surplus:

$$\max_{g,d,L} U + V = \max_{g,d,L} u(g, L) + v(g, d) - c(g) - c(L) - c(d)$$

Note that when an agreement is signed we assume that the sequence of actions is as follows: F_S first chooses L, and given L it also chooses g. Then observing these choices, F_N will choose d. Solving backward, F_N invests optimally in development $d = d^*(g)$ given the provision of genetic material g:

$$\frac{\partial v}{\partial d}(g, d^*(g)) = c'(d^*(g)) \tag{1}$$

Then F_S chooses the level of genetic resources $g = g^*(L)$:

$$\frac{\partial u}{\partial g}(g^*(L), L) + \frac{\partial v}{\partial g}(g^*(L), d^*(g^*(L))) = c'(g^*(L)) \tag{2}$$

Finally, the choice of investment in land use L is determined by:

$$\frac{\partial u}{\partial L}(g^*, L^*) = c'(L^*) \tag{3}$$

where $g^* = g^*(L^*)$ and $d^* = d^*(g^*)$. Thus, when property rights are universally recognised and enforced, bargaining yields an efficient outcome from the industry perspective. This solution sets the benchmark against which all comparisons will be made.

Autarky The autarky situation can be seen as the situation where F_N and F_S fail to reach an agreement and F_S can credibly commit to deny F_N access to her resources or possibly prevent unauthorised use (or biopiracy). The payoff functions in autarky are given by:

$$\begin{aligned} U^a &= u(g, L) - c(g) - c(L) \\ V^a &= 0 \end{aligned}$$

The first expression indicates that F_S benefits from the medicine derived from the genetic resources g to address diseases occurring in the South. The second expression represents F_N's payoff when he is denied access to g and cannot develop a new patentable drug based on g. F_S will unilaterally choose the level of genetic resources g^a and land use L^a to maximise her payoff, i.e.

$$\frac{\partial u}{\partial g}(g^a, L^a) = c'(g^a) \tag{4}$$

$$\frac{\partial u}{\partial L}(g^a, L^a) = c'(L^a) \tag{5}$$

Comparing (4) and (5) to the optimal outcomes in (2) and (3), shows that autarky is sub-optimal: $g^a < g^*$ and $L^a < L^*$. Equation (4) indicates that F_S fails to internalise the effect g on F_N. In addition, investment in L is smaller in autarky.[2]

We now wish to investigate how the uncertainty about the recognition of the right by courts in the North affects on the one hand, the incentive to invest in genetic diversity L and supply genetic resources g, and on the other hand, the incentive to develop drugs d derived from these genetic resources.

3.4 Bargaining over genetic resources under uncertain *ex ante* enforceability

At time t_1, F_N and F_S bargain over the access to the genetic resources g according to the Nash bargaining solution. The share of the surplus that F_S will extract depends on her bargaining position, which in turn depends F_S's *outside option*, i.e. her payoff if bargaining breaks down permanently. Binmore, Rubinstein and Wolinsky (1986) and Binmore, Shaked and Sutton (1989) have shown that an outside option affects the equilibrium outcome in Nash bargaining, only if at least one of the parties prefers this outcome to an agreement in the absence of the outside option. This is the outside option principle. They also clearly distinguish an outside option from a *threat point* which is the *status quo* value that the two parties earn while they are in disagreement but still bargaining. The threat point of the negotiation here is therefore given by the autarky payoffs $(U^a; V^a = 0)$. F_N and F_S solve the following bargaining problem:

$$\max_{U,V} (U - U^a)^\alpha (V - V^a)^{1-\alpha} \text{ s.t. } U \geq U^{os} \tag{6}$$

[2]For any L, $\left(\frac{\partial u}{\partial L}(g^*, L) > \frac{\partial u}{\partial L}(g^a, L)\right)$ as the cross derivative of u is positive by assumption. Then for $L = L^a$, $\left(\frac{\partial u}{\partial L}(g^*, L^a) > \frac{\partial u}{\partial L}(g^a, L^a) = c'(L^a)\right)$. As the marginal cost is increasing in L and $\frac{\partial u}{\partial L}(g^*, L)$ is decreasing in L then the equality between marginal cost and marginal benefit is re-established if and only if L increases. Therefore, it must be the case that $L^* > L^a$.

where U^{os} is F_S's outside option payoff; α and $1-\alpha$ are F_S's and F_N's bargaining power.

The presence of the outside option affects the equilibrium outcome only if F_S prefers U^{os} to an agreed payoff U characterising the equilibrium in the absence of the outside option. Any offer below U^{os} will be rejected. Similarly, an offer exceeding U^{os} will be a waste for F_N since F_S would accept the contract for less. In the equilibrium (subgame perfect equilibrium), F_N will offer at t_1 a contract that provides F_S no more than her outside option, $U = U^{os}$. Our task now is to determine F_S's outside option depending on the ruling made by the court. If the court holds that there is an infringement in F_S's right, the chosen remedy is either an injunction rule or a damage rule. In contrast, if the court rules that there is no infringement then an open access regime is legitimised. The corresponding payoffs are formalised as $U^{os} = \{EU_1, EU_2\}$ where EU_1 and EU_2 are F_S's expected payoffs when bargaining takes place respectively, under the shadow of the injunction rule and the damage rule. The court's decision has clearly a key role in determining the distribution of the surplus.

3.4.1 Outside Option 1: Bargaining under the shadow of injunction.

Choice of g and d before the court's ruling. With probability ξ, the court chooses to enforce F_S's right. Under the injunction rule, $F_N$is not allowed to produce and market a drug derived from g. In the eventuality of infringement, court-induced payoffs are $\Psi_S^I = u(g,L) - c(g) - c(L)$ for F_S and $\Psi_N^I = -c(d)$ for F_N. With probability $1-\xi$, there is no infringement, which implies that F_N benefits from the open access to g and does not require F_S's prior consent. The payoffs are then $\Psi_S^{OA} = u(g,L) - c(g) - c(L)$ and $\Psi_N^{OA} = v(g,d) - c(d)$.

F_S and F_N choose the genetic resource level g and investment in d before the court in the North makes its decision. Investment L is predetermined at the time these choices are made. The expected payoffs derived from the court's ruling are:

$$\begin{aligned} \overline{U}_1 &= u(g,L) - c(g) - c(L) \\ \overline{V}_1 &= (1-\xi)v(g,d) - c(d) \end{aligned}$$

We first determine the level of genetic resources g and drug development d chosen by F_S and F_N. Given investment L, F_S and F_N will choose $\hat{g}_1 = g(L)$ and $\hat{d}_1 = d(\hat{g}_1)$ such that:

$$\frac{\partial u}{\partial g}(\hat{g}_1, L) = c'(\hat{g}_1) \tag{7}$$

$$(1-\xi)\frac{\partial v}{\partial d}(\hat{g}_1, \hat{d}_1) = c'(\hat{d}_1) \tag{8}$$

Comparing (2) with (7) suggests that $\hat{g}_1$ is sub-optimal. The supply of g is inefficient, $\hat{g}_1 < g^*$ because like in the autarky regime, F_S fails to internalise the benefit from g that accrues to F_N. Investment in drug development is also sub-optimal, $\hat{d}_1 < d^*$ as F_N discounts the uncertainty about the court's ruling. F_N would like to choose an optimal level of d to fully take advantage of the open access regime (free riding regime) but he refrains from such investment because *ex post* the enforcement of the right would prevent him from marketing a drug derived from g. Finally, the low level of g also affects investment in d.

Court enforces the right. Once these choices are made, the court's ruling will resolve the uncertainty about the enforceability of the right. If the court enforces the right, i.e. $\xi = 1$, and enjoins F_N to stop its activity, the two parties are free to renegotiate over g. F_N now requires a license from F_S to use the genetic resources. Moreover, the inefficiency of $\hat{g}_1$ makes renegotiation mutually beneficial. The threat point or *status quo* of this renegotiation is determined by the court-induced payoffs defined above. The threat point therefore shifts from the autarky position to the point $\Big(-c(\hat{d}_1); u(\hat{g}_1, L) - c(\hat{g}_1) - c(L)\Big)$ where F_N's bargaining position is weakened as his payoff decreases while F_S's payoff remains unchanged. The Nash bargaining outcome results in the following division of the benefits:

$$\begin{aligned}
U^I &= u(\hat{g}_1, L) - c(\hat{g}_1) - c(L) + \alpha \left[u(g, L) + v(g, \hat{d}_1) - c(g) - u(\hat{g}_1, L) + c(\hat{g}_1)\right] \\
V^I &= -c(\hat{d}_1) + (1-\alpha) \left[u(g, L) + v(g, \hat{d}_1) - c(g) - u(\hat{g}_1, L) + c(\hat{g}_1)\right]
\end{aligned}$$

No enforcement of the right. If the Northern court does not enforce the property right granted in the South, i.e. $\xi = 0$, F_S cannot prevent F_N from getting access to her genetic resources and derive a new marketable drug from them. This situation is akin to an open access regime. No license is required from F_N so that he can use g as a free good without compensating F_S. Despite the inefficiency of $\hat{g}_1$, renegotiation over g will not take place. Indeed, with the certainty that F_S is denied her right over g in the North, nothing prevents F_N from reneging on contractual obligations. The division of profits in the open access regime is: $U^{OA} = \Psi_S^{OA}(\hat{g}_1, L) = u(\hat{g}_1, L) - c(\hat{g}_1) - c(L)$ and $V^{OA} = \Psi_N^{OA}(\hat{g}_1, \hat{d}_1) = v(\hat{g}_1, \hat{d}_1) - c(\hat{d}_1)$.

Given these payoffs, F_N decides to engage in drug development if and only if $EV_1 = \xi V^I + (1-\xi)V^{OA} \geq V^a$, that is:

$$(1-\alpha)\xi\left[u(g,L)+v(g,\hat{d}_1)-c(g)-u(\hat{g}_1,L)+c(\hat{g}_1)\right]+(1-\xi)v(\hat{g}_1,\hat{d}_1) \quad \geq \quad c(\hat{d}_1) \tag{9}$$

When this condition is not satisfied (generally when α and ξ are large enough, e.g. if $\alpha = 1$ and $\xi = 1$) the autarky regime will ensue.

F_S's investment decision. Foreseeing these outcomes, at time t_0, F_S unilaterally chooses the level of L that maximises his expected payoff $EU_1 = \xi U^I + (1-\xi)U^{OA}$:

$$EU_1 = u(\hat{g}_1,L)-c(\hat{g}_1)-c(L)+\alpha\xi\left[u(g^*(L),L)+v(g^*(L),\hat{d}_1)-c(g^*(L))-u(\hat{g}_1,L)+c(\hat{g}_1)\right] \tag{10}$$

The first order condition with respect to L yields:

$$\alpha\xi\frac{\partial u}{\partial L}(g^*(\hat{L}_1),\hat{L}_1)+(1-\alpha\xi)\frac{\partial u}{\partial L}(\hat{g}(\hat{L}_1),\hat{L}_1)=c'(\hat{L}_1) \tag{11}$$

Full efficiency of L requires F_S to appropriate the marginal social benefit generated by the investment. Equation (11) indicates that F_S's marginal private benefit differs from the marginal social benefit as characterised in (3) so the investment level $\hat{L}_1$ is not efficient ($\hat{L}_1 < L^*$). This implies that $g^*(\hat{L}_1)$ is not socially optimal either, even though the genetic resources g are supplied efficiently given L. The first term on the LHS in equation (11) indicates the expected share of the marginal social benefit from investment captured by F_S through renegotiation. The second term suggests that F_S also weighs the effect of his investment on the noncooperative outcome although this outcome does not actually arise in the renegotiation equilibrium. (Grossman and Hart 1986) In other words, F_S cares about how her investment in L affects the court-induced *status quo* $\Psi^I_S(\hat{g}_1, L)$ in addition to the social benefit derived from the cooperative outcome. Unlike the efficient outcome in (3), F_S's choice now depends on the the *status quo* before renegotiation, the distribution of bargaining power and the probability of infringement. F_S faces a typical hold up problem: she underinvests because she is unable to appropriate entirely the fruits of her investment while bearing the whole cost. Only when $\alpha = 1$ and $\xi = 1$ can L be socially optimal. However, with these parameter values, condition (9) does not hold. Thus, investment in maintaining genetic diversity is sub-optimal ($\hat{L}_1 < L^*$) when the two firms bargain under the shadow of injunction. The lower F_S's bargaining power, the more benefit is captured by F_N, and the lower the investment in conservation. In addition, the more unlikely F_S thinks the court will enforce her right, i.e. the smaller ξ, the less investment will be undertaken.

Proposition 1:

When the court in the North rules under the shadow of an injunction:

1) If (9) holds, F_S faces a hold-up problem so that investment in L is sub-optimal $\hat{L}_1 < L^*$. Moreover, F_N will free ride but will underinvest due to the uncertainty ξ about the enforceability of F_S's property right in the North: $\hat{d}_1 < d^*$.

2) If (9) does not hold, the autarky regime prevails as free riding is deterred. We then have: $\hat{L}_1 = L^a$, $\hat{g}_1 = g^a$, and $\hat{d}_1 = 0$.

3.4.2 Outside option 2: Bargaining under the shadow of the damage rule

Choice of g and d before the court's ruling. With probability ξ, the court in the North enforces the right and we now assume that it relies on the damage rule. F_N develops and sells a new product derived from the genetic resources and receives $v(g,d)-c(d)$. However, he is ordered to pay $D(g,d)$ in damages for using g without F_S's prior consent. The payoffs induced by the damage rule are $\Psi_S^D = u(g,L)+D(g,d)-c(g)-c(L)$ and $\Psi_N^D = v(g,d)-D(g,d)-c(d)$. With probability $1-\xi$, the right is not enforced so that F_N and F_S receive the open access payoffs defined in the previous section. The expected payoffs induced by the court's ruling are then given by:

$$\begin{aligned}\overline{U}_2 &= u(g,L)+\xi D(g,d)-c(g)-c(L)\\ \overline{V}_2 &= v(g,d)-\xi D(g,d)-c(d)\end{aligned}$$

Assumption:

1) The damage $D(g,d)$ is strictly positive, increasing and concave in g and d.

2) $\Psi_N^D = v(g,d)-D(g,d)-c(d) \geq 0$

The second assumption is a limited liability assumption as the damage cannot exceed F_N's net earning.[3] The rationale is that the court in the North may want F_N to continue his activity while giving F_S enough incentive to invest and provide useful information. Damage payment depends obviously on g but also on d. This is because we assume that F_N is forced to compensate F_S based on the ill-gotten profit that he has made, and not based on F_S's profit loss, which is irrelevant in this model. (see Schankerman and Scotchmer, 2001)

[3]This assumption implies that a condition equivalent to (9) for the damage rule, i.e. $EV_2 = \xi V^D + (1-\xi)V^{OA} \geq 0$ is always satisfied.

Given investment L, F_S and F_N choose unilaterally $\hat{g}_2 = g(L)$ and $\hat{d}_2 = d(\hat{g}_2)$ that maximise $\overline{U}_2$ and $\overline{V}_2$ such that:

$$\frac{\partial u}{\partial g}(\hat{g}_2, L) + \xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) = c'(\hat{g}_2) \tag{12}$$

$$\frac{\partial v}{\partial d}(\hat{g}_2, \hat{d}_2) - \xi \frac{\partial D}{\partial d}(\hat{g}_2, \hat{d}_2) = c'(\hat{d}_2) \tag{13}$$

In the equilibrium, investment in d must equalise F_N's net private marginal benefit—consisting of his marginal benefit minus the expected marginal damage payment—with the marginal cost. Investment in drug development $\hat{d}_2$ is generally not set optimally unless $\xi \frac{\partial D}{\partial d}(\hat{g}_2, \hat{d}_2) = 0$. In general, the existence of uncertainty about enforcement combined with the positive effect of d on damages lead F_N to restrict his investment.

Besides, the equilibrium level of genetic resources $\hat{g}_2$ must balance at the margin, the sum of F_S's benefit and expected damage, with the cost of supply. The choice of a particular damage scheme by the court has a major effect on F_S's incentives to supply genetic resources. A necessary and sufficient condition for $\hat{g}_2$ to be unilaterally optimal given L is that $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) = \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$, i.e. the expected marginal damage is equal to F_N's marginal benefit from g. When this condition holds, F_S can fully internalise the external effect of g on F_N. The information required for the court to set the right damage scheme may however be considerable. So, in general, it is most likely that $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) \neq \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$, which implies a sub-optimal level of g. If $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) \lesseqgtr \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$ then $\hat{g}_2 \lesseqgtr g^*$. The smaller ξ, the smaller the expected marginal damage and therefore the more likely access will be restricted.

Case 1 – General Case: $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) \neq \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$

Court enforces the right. Uncertainty over the enforcement of the right is resolved once the court has enjoined F_N to pay damages to F_S ($\xi = 1$). As $\hat{g}_2$ is not set at the efficient level, the two parties are free to renegotiate a licensing contract that allows F_N to benefit from an optimal supply of genetic resources given L. The threat point or *status quo* in this renegotiation shifts from the autarky position to the court-induced payoffs determined above $\Big(v(\hat{g}_2, \hat{d}_2) - D(\hat{g}_2, \hat{d}_2) - c(\hat{d}_2); u(\hat{g}_2, L) + D(\hat{g}_2, \hat{d}_2) - c(\hat{g}_2)\Big)$. Relative to autarky, both F_S's and F_N's payoffs increase in this new threat point. The renegotiation outcome will then be given by:

$$
\begin{aligned}
U^D &= u(\hat{g}_2, L) + D(\hat{g}_2, \hat{d}_2) - c(\hat{g}_2) - c(L) + \alpha \left[u(g, L) + v(g, \hat{d}_2) - c(g) - u(\hat{g}_2, L) + c(\hat{g}_2) - v(\hat{g}_2, \hat{d}_2) \right] \\
V^D &= v(\hat{g}_2, \hat{d}_2) - D(\hat{g}_2, \hat{d}_2) - c(\hat{d}_2) + (1-\alpha) \left[u(g, L) + v(g, \hat{d}_2) - c(g) - u(\hat{g}_2, L) + c(\hat{g}_2) - v(\hat{g}_2, \hat{d}_2) \right]
\end{aligned}
$$

Court does not enforce the right. If however, no damage payment is ordered to F_N then uncertainty is resolved with $\xi = 0$. That is, the property right is not recognised in the North and open access of g ensues. No renegotiation over g will take place for the reason invoked earlier in the case of injunction. The payoffs of the open access regime are now given by: $U_2^{OA} = \Psi_S^D(\hat{g}_2, L) = u(\hat{g}_2, L) - c(\hat{g}_2) - c(L)$ and $V_2^{OA} = \Psi_S^D(\hat{g}_2, \hat{d}_2) = v(\hat{g}_2, \hat{d}_2) - c(\hat{d}_2)$.

F_S's investment decision. Anticipating these possible outcomes, at time t_0, F_S will choose L to maximise her expected payoff:

$$
\begin{aligned}
EU_2 &= u(\hat{g}_2, L) + \xi D(\hat{g}_2, \hat{d}_2) - c(\hat{g}_2) - c(L) \\
&+ \alpha\xi \left[u(g^*(L), L) + v(g^*(L), \hat{d}_2) - c(g^*(L)) - u(\hat{g}_2, L) + c(\hat{g}_2) - v(\hat{g}_2, \hat{d}_2) \right]
\end{aligned} \tag{14}
$$

Investment in conservation L is derived from the first order condition:

$$
\alpha\xi \frac{\partial u}{\partial L}(g^*(\hat{L}_2), \hat{L}_2) + (1 - \alpha\xi) \frac{\partial u}{\partial L}(\hat{g}_2, \hat{L}_2) = c'(\hat{L}_2) \tag{15}
$$

When $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) < \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$, the analysis is very similar to the one we made earlier under the injunction rule and F_S faces the same incentive problem. For the reasons invoked earlier, F_S faces a hold-up problem and underinvests in maintaining genetic diversity, $\hat{L}_2 < L^*$.

When $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) > \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$, F_S will overinvest in L, i.e. $\hat{L}_2 > L^*$. The fact that F_S values the effect of L on the threat point causes her to overinvest as $\hat{g}_2 > g^*$. This case may be unlikely as the court in the North may be unwilling to grant such favourable compensation to F_S. Alternatively, this may suggest that F_S preserves land that is not rich in biodiversity. This is inefficient as such land could be put to better use, for example for farming. Finally, the lower the common belief ξ about the infringement ruling, the less likely it is that this condition will hold.

Case 2 – Special Case: $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) = \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$

A sufficient condition for this equality to hold is for example $\xi D(g,d) = v(g,d) - K(d)$, i.e. F_N is expected to disgorge part of his benefits but retains the amount $K(d) - c(d)$—where $K(d)$ is increasing and concave in d. In this case, the payoffs are: $U^D = u(\hat{g}_2, L) + v(\hat{g}_2, \hat{d}_2) - c(\hat{g}_2) - K(\hat{d}_2) - c(L)$ and $V^D = K(\hat{d}_2) - c(\hat{d}_2)$. The supply of genetic resources is then efficient given L so that $\hat{g}_2 = g^*(L)$. Therefore, no renegotiation will take place. Expecting this outcome, at time t_0, S will choose L to maximise her expected payoff:

$$EU_2 = U^D = u(g^*(L), L) - c(g^*(L)) - c(L) + v(g^*(L), \hat{d}_2) - K(\hat{d}_2) \tag{16}$$

The first order condition then yields the optimal investment $L_2 = L^*$.

When $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) = \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$, the damage payment gives F_S the proper incentive to fully internalise the externality of g. In fact, the court makes F_S the residual claimant of the surplus created by her investment by allowing F_N to retain $K(\hat{d}_2) - c(\hat{d}_2)$ and allowing F_S to receive the residual benefit. As a result, F_S will appropriate the entire return on her investment. If the optimality of F_S's investment is the objective for the Northern court, the careful design of the damage scheme is of particular importance. However, given the considerable information required to achieve this goal, this outcome may prove a difficult target.

Proposition 2:

The choice of the damage scheme affects both parties' incentive to invest:

1) If $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) < \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$*,* F_S *underinvests in the maintainance of genetic diversity,* $\hat{L}_2 < L^*$*.*

2) If $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) = \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$*,* F_S *optimally invests in the maintainance of genetic diversity,* $\hat{L}_2 = L^*$*.*

3) If $\xi \frac{\partial D}{\partial g}(\hat{g}_2, \hat{d}_2) > \frac{\partial v}{\partial g}(\hat{g}_2, \hat{d}_2)$*,* F_S *overinvests in the maintainance of genetic diversity,* $\hat{L}_2 > L^*$*.*

4) Moreover, in all these cases, drug development is sub-optimal $\hat{d}_2 < d^*$ *because the payment of the damage prevents* F_N *to appropriate the whole return on his investment.*

3.5 Discussion

If F_S's right in g was recognised *ex ante* in the North and enforced, the optimal solution would be achieved despite the non contractibility of investment L. This is because the contract over g would channel all the benefit generated by F_S via a transfer payment, providing F_S enough incentive to invest optimally in L. The problem here comes from the uncertainty about the *ex ante* enforceability of the property right in the informational good g. The IPR system in the North does not generally confer exclusive rights in *products of nature* unless they are distinct enough from their forms in the wilderness. Invention rather than discovery is the basis for appropriation in that system.[4] This excludes much of the South own innovations or knowledge because they are often hard to distinguish from the genetic resources as such. Absent the *ex ante* enforceability of the right in g, F_S may suspect that F_N will free ride on her contribution and use g as a free good to develop new drugs without any compensation. By rejecting F_N's offer, F_S has the power to hold up F_N's innovation. This allows her to establish a stronger bargaining position in the negotiation and seek *ex post* recognition and enforcement of her right in Northern courts. By doing so, F_S faces the hold-up problem as the renegotiation after uncertainty is resolved by the court's decision allows F_N to capture some of the benefits created by her investment in L.[5] This problem of appropriation causes F_S to restrict her

[4] In Diamond vs. Chakrabarty (1980), the case that first allowed the patenting of microorganisms, the court held that the microorganism in question, a human-made genetically engineered bacterium capable of breaking down components of crude oil, which could not be done by any naturally occurring bacteria, was patentable. (Rodriguez-Stevenson, 2000)

[5] Both parties have incentive to renegotiate: F_N, because 1) g is not unilaterally set efficiently by F_S; and 2) he can no longer sell the new drug without a license under injunction; and F_S, because she can increase her payoff relative to autarky.

investment in maintaining genetic diversity.

The court in the North plays a key role both in inducing efficiency and shaping the division of the profit by altering the bargaining position of the two parties through its ruling. Enforcement of the property right shifts the threat point away from the autarky position to a new *status quo* induced by the court's decision and dependent upon the chosen remedy. The choice of the remedy—injunction rule or damage rule—matters as it leads to different incentives to invest in preserving biodiversity and developing drugs.

The damage rule induces both a higher unilateral genetic resource supply and more investment in the maintenance of genetic diversity. This is because unlike injunctions, damages allow F_S to partly internalise the benefit from g accruing to F_N. The use of damages thus mitigates the hold-up problem since the award of a compensation provides incentives for increased investment compared to the award of an injunction, i.e. $\hat{L}_2 \geq \hat{L}_1$. Under specific conditions, damages can lead to a socially optimal investment in genetic diversity. This is the case when the court makes F_S the residual claimant of the surplus created by her investment. Overinvestment in L can even occur if the expected marginal damage is greater than F_N's marginal benefit from g. This is inefficient and suggests that non-biodiverse land is being conserved at the expense of more beneficial uses. The potentially high uncertainty about enforcement makes however this outcome unlikely: the lower ξ, the less likely overinvestment in L is.

Drug development is not optimal because of the *ex ante* uncertainty over enforcement. Given this uncertainty, investment in drug development d depends on the choice of the remedy. When the court seeks to encourage drug development, the choice of the remedy should depend on the relative magnitude of the marginal benefit under the injunction rule $(1-\xi)\dfrac{\partial v}{\partial d}(\hat{g}_1, \hat{d}_1)$ and the marginal benefit under the damage rule $\dfrac{\partial v}{\partial d}(\hat{g}_2, \hat{d}_2) - \xi\dfrac{\partial D}{\partial d}(\hat{g}_2, \hat{d}_2)$. The choice of the remedy then hinges upon the *ex ante* common belief about infringement ξ and the effect of drug development on the damage.

Our model suggests that despite the introduction of a property right in the genetic resources, investment in maintaining biological diversity may be sub-optimal given the uncertainty about the enforcement of the right across jurisdictions. Once investment costs are sunk and genetic information diffused, F_N might opportunistically capture this information without F_S's consent and exploit it for his own private benefit. This situation may eventually lead to renegotiation in which F_S's rent is dissipated causing her to underinvest. The court can however under certain conditions restore optimality by imposing a liability rule that makes F_S the residual claimant of the benefits generated by her investment.

4 Conclusion

The literature on the use of biodiversity for the purpose of R&D and bioprospecting often focuses on the issue of access to genetic materials and traditional knowledge. In this paper, our analysis insists primarily on the incentive problem for land conservation in the context of sequential R&D. We believe that investment in environmental stewardship to maintain biodiversity is a fundamental issue in this area. As genetic material and traditional knowledge (TK) are derived from the observation and knowledge about biodiversity, the irreversible loss of biodiversity would make discussion on access to genetic resources and TK meaningless. In this sense, investment in maintaining diversity is a necessary condition for information to flow across the sequential R&D process in the life sciences.

In this respect, the main issue is the hold-up problem stemming from the absence of coordination of the North and South legal systems to recognise and enforce property rights on informational goods across jurisdictions. Legal institutions—in particular the court in the Northern region—play a crucial role in this paper. The decision of the court—injunction, damage or open access—has an impact both for the efficiency of investment and the distribution of the benefits. In the face of the uncertainty about the enforcement, by Northern courts, of the rights conferred in the South, Southern firms are likely to underinvest in maintaining genetic diversity as they will bear all investment costs but will receive only part of the return. As a result, the genetic information flowing from the primary to the secondary stage of the sequential R&D process is generally inefficient. Uncertainty also prevents firms in the North to undertake socially optimal drug development.

Thus, in this paper we point to the necessity of coordinating the legal systems of the two regions to create the basis for socially optimal investment in land conservation and efficient exchange of information between North and South. Under such system, efficiency need not come from court's intervention but rather from cooperation between the parties.

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