Center for Economic Studies, University of Munich, 80539 Munich, Germany

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COMPETING FOR CLAIMS TO PROPERTY

Stergios Skaperdas
Constantinos Syropoulos

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Center for Economic Studies
University of Munich
Schackstr. 4
80539 Munich
Germany
Telephone & Telefax:
++49-89-2180-3112

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Abstract

Existing work on the costs of insecure property has largely focused on the overexploitation problem of common pool resources. We investigate other costs of insecure resources - including uncertainty costs, lack of tradeability, and conflict - within a setting in which adversaries compete for claims to an insecure resource by making choices between production and appropriation. We also examine the different types of regimes or conventions about settling disputes that can arise in our setting: winner-take-all conflict; contracting to divide the contested resource; and contracting to divide the resource with the possibility of trade in other commodities. We find conditions under which insecure property can lead one or more agents to *ex ante* prefer not to trade and thus have an incentive to commit not to trade. For each regime we consider, we derive comparative static results and show how, regardless of the regime, claims to property systematically vary with the characteristics of the adversaries.

Stergios Skaperdas
Department of Economics
University of California
Irvine, CA 92717
USA

Constantinos Syropoulos
Department of Economics
Pennsylvania State University
University Park, PA 16802
USA

I. Introduction

All economies have, in varying degrees, resources with unclear or insecure ownership. In many developing and post-Soviet economies especially, insecure ownership can extend to assets that are central to the functioning of the economy: physical capital, land, natural resources. Although such a condition can be expected to harm economic activity, extant economic theory provides little guidance in making a coherent assessment of the adverse effects of insecure property. The competitive paradigm, for instance, cannot even address the issue since it supposes that property rights on all initial endowments of all agents in the economy are completely specified and enforced.

To be sure, the overexploitation of common pool resources (e.g., fisheries, unregulated commons) in the presence of open access is a problem well-known and well-analyzed by economists.[1] Only some insecure resources, however, are subject to open access; capital equipment or agricultural land, for example, often are not. Then one problem with insecure property may easily be the opposite of overexploitation: while their ownership is under dispute, capital equipment may be idled and agricultural land may remain fallow or used just for pasture. But even if one party were to have temporary possession of a still contested resource and were able to exclude others from its use, he or she might have trouble taking full advantage of such possession since the tradeability of an insecure resource is limited. That is, insecure ownership reduces the value of an economic resource by rendering its exchange difficult or uncertain. Moreover, the mere presence of a contested resource often causes the diversion of other economic resources into a costly contest for its capture

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[1] Starting with Gordon (1954) the literature on the topic is large. The comparative examination of different forms of property has largely contrasted private property to an open access regime (Demsetz, 1967, Cohen and Weitzman, 1973, and the survey by Furubotn and Pejovich, 1972). As argued by Ostrom (1990), Stevenson (1991), and others, however, an open access regime should not be confused with common property, the latter being a "property" regime which limits access and at least partly remedies the overexploitation problem.

through arming, lobbying, or litigation.

Though several authors have gone beyond the overexploitation problem of open access resources and have addressed one or more of the above issues,[2] there has not been a systematic analysis of the different effects of insecure property within a single framework. In this paper we seek to at least partly remedy this omission.

We focus on contests among individuals or groups for an insecure resource, with each party trying to establish positions favorable to its interests with the actual or potential use of force as the ultimate basis of agreements. The contest for the insecure resource is embedded within a simple general equilibrium model, a feature which allows us to analytically and pictorially identify the different types of costs of insecure property: those due to arming, and more generally to appropriative activities; others due to the lack of tradeability; and still others emanating from the uncertainty about who will be able to exploit the contested resource.

The quantitative importance of each type of cost varies with the regime - the convention - that the concerned agents expect to prevail. In the absence of enforceable formal arrangements for settling claims to property, a wide variety of conventions can exist across different societies ranging from open conflict to customs that can lead to low resource waste.[3] While we do not concentrate on which convention

[2] Umbeck (1981) has examined the development of property claims during the California gold-rush emphasizing, as we do, the role of violence. Similarly, Johnsen (1986) has considered the formation of property rights among some Indian tribes in British Columbia. Libecap (1989) considered the role of distributional struggles in establishing property rights, whereas Feder and Feeny (1991) have brought attention to the limitation on credit markets (that is, limitations on intertemporal trading) brought about by insecure property rights. De Meza and Gould (1992) take account of the costs of making property private, of enclosing the commons. Grossman and Kim (1995) differentiate between defensive and offensive arming and are particularly interested in equilibria with only defense, a condition with private enforcement of property rights.

Some economic historians have also emphasized the role of violence in the establishment of modern states in Europe (Lane, 1958, Tilly, 1985).

[3] See Libecap (1989) and Ostrom (1990) for a multitude of examples of conventions and property rights institutions, with widely differing efficiency properties.

or regime is more likely to evolve, our framework at least allows for a classification of regimes and their comparison. These regimes include: winner-take-all conflict; settlement to divide the contested resource under the threat of conflict; and settlement to divide the resource, again under the threat of conflict, but also under the expectation that the contested resource or other commodities will be subsequently traded. We first examine each of these three possible regimes separately and find that, despite their differences, there exist regularities that hold across them. For example, the richer parties have higher probability of winning under conflict or receive higher portions of the pie under the two settlement regimes compared to their poorer competitors. Though common-sensical, such properties are not obtained in models of rent-seeking that have some formal similarities to our model but which are partial equilibrium in nature and cannot distinguish among the different regimes.[4]

We then compare the three regimes. When the competing parties expect to trade, the pie over which they compete is bigger than the one without the prospect of trade, a feature that may render arming relatively more attractive when trade is expected than when it is not. If the gains from trade are sufficiently small relative to the resource cost of arming under trade, trade may be welfare-reducing for one or both parties *ex ante* (i.e., with an endogenously determined level of "arms").[5] Thus we

[4] Starting with Tullock (1980), this related literature includes Nitzan (1991), Perez-Castrillo and Verdier (1992), and many others. Although our model can be interpreted as a general equilibrium model of rent-seeking, it formally differs in that it studies competition for an insecure resource rather than competition for rents. Skaperdas and Gan (1995) can distinguish between conflict and settlement in contests with risk averse adversaries.

Krueger (1974), Findlay and Wellisz (1982), Magee et. al. (1989) also explore contests between factors with competing interests over quota rents and tariff policies in the context of general equilibrium trade models. However, beyond this formal similarity the concerns of these studies differ from those of this paper.

[5] That autarky may dominate free trade in the presence of distortions is a well-known proposition in the trade literature (see e.g., Bhagwati, 1971). One of our contributions to this literature is to illustrate this possibility in the presence of insecure property. A second contribution lies in that we identify plausible conditions on endowments and technology under which one or more of the competing parties would *ex ante* prefer not to engage in trade once the contested resource has

show how the presence of insecure ownership can lead to the imposition of trade restrictions. Insecure ownership has been a hitherto unexplored rationale for trade restrictions but, given the historical prevalence of insecure ownership and conflict, it might have been, or may still be, empirically important.

In addition to studies of rent-seeking that we identified earlier (footnote 4), the interpretation we have maintained in the main body of this paper is related to the literature studying settings in which agents make choices between useful production and appropriation.[6] One difference with most of this earlier work is that we study the implications of arming and conflict over the capture of one economic resource rather than over the whole economic product. Thus, instead of a more abstract state of nature, the economic environment within which agents interact in this paper is closer to that found in many of today's economies where there is some room for predation but without being completely generalized. More importantly, our framework generates a simple breakdown of the costs of insecure property and allows for different types of competition for an insecure resource, including the possibility of engaging in arming and trading with an adversary.[7]

In Section II we specify and examine the basic model under winner-take-all conflict. In Section III we identify the possibilities of settlement and trade under

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been divided.

[6] This literature includes papers which focus on conflict among nations (Garfinkel, 1990), conflict among social classes (Usher, 1989, Grossman, 1991, 1994), conflict in general (Tullock, 1974, Hirshleifer, 1988, Rider, 1993, Neary, 1995), legal conflicts (Gould, 1973), and interactions in the absence of property rights (Bush and Mayer, 1974, Skaperdas, 1992, Wärneryd, 1993, Skaperdas and Syropoulos, 1995, Hirshleifer, 1995).

[7] We believe the only other model that can generate such a result nontrivially is Grossman's (1991). The modelling specifics, however, are rather different and Grossman concentrates on other issues.

In a companion paper (Skaperdas and Syropoulos, 1994) we use the same framework as here with specific functional forms while allowing the possibility of perfectly competitive trade taking place (instead of, as we do here, having the terms of trade being determined by bargaining). There we find conditions under which even conflict could be *ex ante* preferable to conflict (or settlement) followed by competitive trade.

the threat of conflict and show the different effects of insecure property. In Sections IV and V we examine, respectively, settlement without trade and settlement with trade, whereas in Section VI we compare the different possible regimes and show how settlement without trade can be a stable regime. In Section VII we conclude.

II. Winner-take-all Conflict

Two agents, labeled 1 and 2, compete for an insecure resource of size T. Each agent i possesses a private inalienable endowment of another resource, L_i, which can be channeled into two activities: One that generates a productive good x_i and another that produces an output y_i which we label as "arms", so that $L_i=x_i+y_i$. The two quantities x_1 and x_2 could represent identical or differentiated commodities.

The welfare of agent i depends on her productive good x_i as well as on the amount of the contestable resource t_i she acquires. Specifically, for every x_i and t_i agent i's welfare is determined by a differentiable function $F^i(t_i,x_i)$ with the following standard properties:

$$\text{(B)}\qquad \begin{aligned} &F^i_t \equiv \partial F^i/\partial t_i>0, \quad F^i_x \equiv \partial F^i/\partial x_i>0, \quad F^i(0,x_i)=0,\\ &F^i_{tt} \equiv \partial^2F^i/\partial t_i^2<0, \quad F^i_{xx} \equiv \partial^2F^i/\partial x_i^2<0, \quad F^i_{tx} \equiv \partial^2F^i/\partial t_i\partial x_i>0, \quad \forall i=1,2. \end{aligned}$$

The function F^i in (B) can be interpreted either as a production function with t_i and x_i as productive inputs, or as a utility function with its arguments thus being conceived as final consumption goods. We hereafter adopt the production interpretation, but the reader should keep in mind that the utility interpretation fits the formal results equally well.

The relative quantities of arms chosen by the two agents determine the probability of each agent winning the entire resource T. Specifically, for a given choice of arms (y_1,y_2) the winning probability of agent 1 is denoted by $p(y_1,y_2)$, with $1-p(y_1,y_2)$ representing agent 2's winning probability. We assume that when both agents possess the same quantity of arms, they have equal winning probabilities and that $p(y_1,y_2)$ is increasing in y_1 but decreasing in y_2. (Thus, the winning probability of each agent is increasing in his own arms allocation and decreasing in that of his opponent.) Formally,[8]

$$\text{(A1)}\quad \begin{array}{l} p(y_1,y_2)\in(0,1); \qquad p(y_1,y_2) = 1-p(y_2,y_1) \quad \forall(y_1,y_2); \\ p(y_1,y_2) \text{ is differentiable; } p_1 \equiv \partial p/\partial y_1 > 0,\ p_2 \equiv \partial p/\partial y_2 < 0. \end{array}$$

The payoff functions for the two agents can now be defined as

$$\text{(1a)}\quad U^1(y_1,y_2) = p(y_1,y_2)\cdot F^1(T,L_1-y_1)$$

$$\text{(1b)}\quad U^2(y_1,y_2) = (1-p(y_1,y_2))\cdot F^2(T,L_2-y_2)$$

As specified, (1) implies that the winner of the contest receives the entire resource T. Thus, the formulation of the payoffs in (1) describes a condition in which both agents believe that conflict, a winner-take-all contest, is the only way to acquire any quantity of the resource T.

With the additional assumptions on p ($\equiv p(y_1,y_2)$) identified below, we have existence [(A2)] and uniqueness [(A2) and (A3)] of pure-strategy equilibrium (please see Theorem 1 in the Appendix).

$$\text{(A2)}\quad p_{11}p \le p_1^2 \quad \text{(and, by symmetry, } -p_{22}(1-p) \le p_2^2;\ p_{11} \equiv \partial^2 p/\partial y_1^2\text{)}$$

$$\text{(A3)}\quad p(y_1,y_2) = f(y_1)/(f(y_1)+f(y_2)) \quad \text{where } f(\cdot)\ge 0,\ f'(\cdot)>0.$$

(A2) is always satisfied when p_{11} is negative, or when an agent's probability of winning the contest is concave in the agent's choice of arms.

[8] Two examples of $p(\cdot,\cdot)$ are:

$p = \exp(ky_1)/(\exp(ky_1)+\exp(ky_2))$ where $k>0$, and

$p = (y_1+c)^m/[(y_1+c)^m+(y_2+c)^m]$ where $m>0$ and $c>0$.

These two functional forms as well as the general class to which they belong (see (A3) below) are axiomatized in Skaperdas (1995).

Let a tilde (~) over variables denote evaluation at an interior equilibrium. Thus, $(\tilde{y}_1,\tilde{y}_2)$ denotes an equilibrium in which both agents choose positive quantities of arms. With subscripts 1 and 2 denoting partial derivatives with respect to y_1 and y_2, the following conditions must be satisfied at an interior equilibrium:

$$\text{(2a)}\quad U_1^1(y_1,y_2) = p_1F^1 - pF_x^1 = 0$$

$$\text{(2b)}\quad U_2^2(y_1,y_2) = -p_2F^2 - (1-p)F_x^2 = 0.$$

The first term of each condition, p_1F^1 for agent 1 and $-p_2F^2$ for agent 2, is the marginal benefit of an infinitesimal change in arms investment, whereas the second term represents the marginal cost of such an investment. Note that the main component of the marginal cost for each agent i is F_x^i, her marginal product of good x_i. In other words, a main component of the opportunity cost of investing in arms is the foregone welfare due to the reduction in x_i caused by positive investments in arms y_i.

Before we proceed to investigate properties of equilibrium, define $\sigma_i \equiv F_t^iF_x^i/(F^iF_{tx}^i)$ (i=1,2). This variable measures the degree of substitutability, and its inverse measures the degree of complementarity, between the two components in the payoff of each agent. When the functions F^i (i=1,2) are homogeneous of degree one, σ_i coincides with the ***elasticity of substitution*** between t_i and x_i. The specification we have adopted here (Assumption (B)) implies that $\sigma_i\in(0,\infty)$. This concept is used in part (b) of Proposition 1 below.

Proposition 1: *Consider a pure-strategy equilibrium* $(\tilde{y}_1,\tilde{y}_2) > (0,0)$. *Then*

(a) $\tilde{y}_1 > \tilde{y}_2$ *iff* $\tilde{F}_x^1/\tilde{F}^1 < \tilde{F}_x^2/\tilde{F}^2$;

(b) $d\tilde{y}_i/dT \gtreqless 0$ *if* $\tilde{\sigma}_1$ and $\tilde{\sigma}_2 \gtreqless 1$ $\quad \forall i$=1,2;

(c) $d\tilde{y}_i/dL_j > 0$ $\quad \forall i,j$=1,2.

To facilitate the interpretation of part (a) of Proposition 1 suppose F^1 and F^2 are Cobb-Douglas functions as indicated in (3) below:

$$F^1(t_1,x_1) = t_1^{\alpha}x_1^{1-\alpha}, \quad \alpha\in(0,1)$$

(3)

$$F^2(t_2,x_2) = t_2^{\beta}x_2^{1-\beta}, \quad \beta\in(0,1).$$

It can be shown that if $L_1=L_2$ in (3), part (a) of the Proposition implies that $\tilde{y}_1>\tilde{y}_2$ if and only if $\alpha>\beta$, or that *the agent who invests more in arms is the one with the highest relative valuation of the prize* T. If, however, we had $\alpha=\beta$ (i.e., the agents' production functions are identical), then we would have $\tilde{y}_1>\tilde{y}_2$ if and only if $L_1-\tilde{y}_1 = \tilde{x}_1 < \tilde{x}_2 = L_2-\tilde{y}_2$, which together imply that $\tilde{y}_1>\tilde{y}_2$ if and only if $L_1>L_2$. Thus, in this case *the agent with the highest initial endowment has a higher probability of winning.* This may help explain the tendency of former Communist party officials in Russia and Eastern Europe for taking over ownership of many formerly publicly-owned (and now disputed) assets and of political and economic power in general. For the former positions of these officials allowed them to accumulate both money and connections relative to others, thus giving them a headstart in the new races for control after the transformation in these countries.

Although intuitively plausible, this and the other results in Proposition 1, as well as other similar ones we will discuss later on, are not obtainable within conventional models of rent-seeking and conflict (e.g., Tullock, 1980, Nitzan, 1991). In these models, the probability of winning or the share of the prize are independent of the agents' endowments. The complementarity between the disputed resource and other factors of production in our model induces the difference with the earlier models.

Continuing further, part (b) of Proposition 1 indicates that *increasing the size of the contestable resource does not always increase the effort expended by the two agents.* Whether it does or not depends on the degree of complementarity between x and t in the functions F^1 and F^2. If both functions exhibit relatively low levels of complementarity (i.e., the σ's are higher than 1), then an increase in the size of the

resource increases the equilibrium arms allocation of both agents. Instead, with high degrees of complementarity between t and the x's, increases in the value of T reduce the effort expended by the agents on producing arms. This may look surprising at first sight, but note that high complementarity of t_i with x_i implies that increases in T reduce its relative scarcity, its marginal valuation, and consequently the need to compete intensely. The flip side of this is that under high complementarity a reduction in T does not only reduce welfare directly (through the limited availability of T) but also indirectly by intensifying competition between the agents. When both σ's are equal to one, a case covering the Cobb-Douglas functions, the equilibrium choice of arms is independent of the size of the contestable resource. The implications for the intensity of competition for different assets in, say, Russia is that it would be lower for very specific assets like machinery and equipment for aluminum production than for assets with more generalized use that can be combined with other inputs in widely different proportions (like undeveloped land in the outskirts of Moscow).

Finally, part (c) of Proposition 1 states that *an increase in the endowment of either agent's resource L_i increases both agents' equilibrium choice of arms.* This apparent intensification of competition as a result of increases in endowments is also found in other models of conflict (Garfinkel, 1990, Skaperdas and Syropoulos, 1995) but is absent from the aforementioned models of rent-seeking that lack complementarity between the prize and the other productive factors.

III. Incentives to Bargain and the Costs of Insecure Property

Retaining the basic structure of the previous section, we now begin to explore the possibility of alternative regimes. We first demonstrate that, once the agents have chosen their arms, both would prefer to bargain and possibly trade rather that enter into conflict. We then decompose the effects of insecure property into three analytically distinct types.

We contend that if, for any choice of arms, the agents (a) could communicate with one another, and (b) were able to physically divide the contestable resource, then it would be in their mutual interest to do so. To see this consider the tree of Figure 1 which depicts one story, though not the only one, of how settlement and conflict may come about. The agents allocate a portion of their primary resource into arms first. Then, each unilaterally declares "war" (W) or "settlement" (S). If at least one agent declares "war" then war emerges as a "winner-take-all" conflict with the payoffs being defined in (1). Settlement can occur only if both agents choose this alternative and the payoffs under this regime have yet to be defined.

Figure 1 about here

To see how both agents can raise their payoffs beyond the levels received under conflict, first note that by assumption (B) $F^1(T,x_1)$ is a strictly concave function of T. Then, recalling that $p \equiv p(y_1,y_2)$ and $x_i = L_i - y_i$ $(i=1,2)$ observe that

(4a) $$F^1(pT,x_1) = F^1(pT+(1-p)0,x_1) > pF^1(T,x_1)+(1-p)F(0,x_1) = pF^1(T,x_1)$$

for agent 1. Similarly, for agent 2 we must have

(4b) $$F^2((1-p)T,x_2) > (1-p)F^2(T,x_2)$$

The relationships in (4) reveal that division of the contestable resource T according to the winning probabilities (i.e., p and 1-p for players 1 and 2 respectively) Pareto-dominates winner-take-all conflict. The division rule p is just one such rule; there exist many other division rules for the resource which are Pareto-superior to conflict.

If, in addition to being able to communicate and divide the resource, the agents were able to trade quantities of the second input (i.e., of x) or of the final good, then there will exist allocations that Pareto-dominate the ones which only involve a

division of the resource T. To see this consider the left-hand-sides of (4a) and (4b). After dividing T according to p, agents 1 and 2 will possess the allocations (pT,x_1) and $((1-p)T,x_2)$ respectively. However, these allocations could generally be improved upon by trading some of x for some of the resource T and then producing the final good(s).

Figure 2 about here

Figure 2, which has been drawn for an arbitrary choice of arms, illustrates the different effects of insecure property. Point A represents the payoff combination under conflict. Line BC is the Pareto frontier when division of the contestable resource is possible; the DE curve is the Pareto frontier when, in addition to division of the resource, trade is also possible; H is the point at which the resource is divided so as to yield a Pareto efficient allocation. Curve FG represents the unconstrained Pareto frontier, the one that would result from the "Nirvana" state in which no arms are chosen, the resource is divided, and efficient trade takes place. That is, FG would be the regular Pareto frontier under secure property. For each choice of arms there is a different disagreement point A and different opportunities sets for division and trade. The more arms the agents choose to have, the closer to the origin are point A and the opportunity sets - except for FG.

Recapitulating, the harmful effects of insecure property can be decomposed into three categories. Starting from the last type, insecure property can constrain trade possibilities and therefore limit the gains from trade. This effect can be identified by the difference between lines DE and BC in Figure 2. The second component of the effects of insecure property can be identified as the difference between line BC (The set of payoff combinations when land is divided) and the conflict payoff pair in A. The last component represents the cost of arming and can be identified by the difference between FG and DE. In the next two sections we examine two sets of regimes, one without and one with trade in x, as the alternatives to the winner-take-all conflict we examined in the previous section.

IV. Settlement I: Contracting to Divide the Contestable Resource

Any division of the contestable resource ultimately depends on the fallback positions of the two agents in the event the division is not consummated. The fallback positions, often called disagreement or threat points, should be identified in this case with the conflict payoffs described in (1). Different choices of arms induce different disagreement points and different payoff possibilities for the two agents, and the possible divisions of the resource that are Pareto optimal conditional on the impossibility of trading for x are numerous. Here we suppose that for each choice of arms the agents will agree on a unique division of the resource, with the share of agent 1 represented by $\gamma(y_1,y_2)$ and thus the share of agent 2 represented by $1-\gamma(y_1,y_2)$.

Having $\gamma(y_1,y_2) = p(y_1,y_2)$ for all (y_1,y_2) would be one possible rule; or, more generally, $\gamma(y_1,y_2)$ could depend on (y_1,y_2) through the function p (i.e., $\gamma(y_1,y_2) = g(p(y_1,y_2))$.[9] Another special case of this rule is $\gamma = \theta\bar{\gamma} + (1-\theta)p$ where $\bar{\gamma} < 1$ and $\theta < 1$ are constants. For θ close enough to 0, the division of the resource is almost wholly determined by the probability of winning in conflict, whereas for θ close enough to 1 the division is almost predetermined, property is secure, and the amount of arms produced by the two agents have minimal effect on the division. Thus, θ could be thought of as a "proxy" measuring the degree of security in the existing property rights structure.

As can be seen from this last example, secure property rights can be considered a special case of a division rule. In the absence of secure property rights, the predictability of a division rule is important (and a second-best solution) in avoiding conflict. The development of such rules as conventions (see Sugden, 1986, Chs. 4 and 5) could be considered an intermediate stage between unpredictability and secure property that may take a long time to evolve. At the end of this section we briefly mention one way of handling cases in which the agents are uncertain about the rule of division or even about whether division will ever occur.

The properties we assume for $\gamma(y_1,y_2)$ are the same as those we have for $p(y_1,y_2)$ in (A1) except for one:

(A1′) $\gamma(y_1,y_2)\in(0,1)$;
$\gamma(\cdot,\cdot)$ is differentiable; $\gamma_1 \equiv \partial\gamma/\partial y_1 > 0$, $\gamma_2 \equiv \partial\gamma/\partial y_2 < 0$.

The difference between (A1′) and (A1) is that we do not impose symmetry here and, consequently, $\gamma(y,y)$ may differ from $\frac{1}{2}$. The reason is that the sharing rule, contrary to the contest success function, should be allowed to depend on the technology and endowment characteristics of the agents since there is no intrinsic reason to expect equal divisions of the resource when both agents choose the same quantities of arms, in the presence of differences in technology or initial endowments. Given the sharing rule $\gamma(\cdot,\cdot)$, the payoff functions of the two agents are:

(5a) $$V^1(y_1,y_2) = F^1\big(\gamma(y_1,y_2)T, L_1-y_1\big)$$

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[9] With the Cobb-Douglas functions in (3), the Nash and Kalai-Smorodinsky bargaining solutions (for an exposition see Roth, 1979) can be shown to have this property. Under (3) the Nash bargaining solution, γ_N, solves the following equation.

$$\alpha\gamma_N^{\alpha-1}[(1-\gamma_N)^\beta-(1-p)] = \beta(1-\gamma_N)^{\beta-1}(\gamma_N^\alpha-p).$$

On the other hand, the Kalai-Smorodinsky solution, γ_K, can be obtained from

$$\frac{\gamma_K^\alpha-p}{(1-\gamma_K)^\beta-(1-p)} = \frac{[1-(1-p)^{1/\beta}]^\alpha-p}{(1-p^{1/\alpha})^\beta-(1-p)}.$$

The same property (i.e., dependence of γ on p) would hold if one of the agents were to take all the surplus, by giving to the other agent just her disagreement payoff. If, for example, agent 2 were to take the entire surplus under (3), agent 1 would receive $(\gamma T)^\alpha x_1^{1-\alpha}=pT^\alpha x_1^{1-\alpha}$, which implies $\gamma(y_1,y_2) = p(y_1,y_2)^{1/\alpha}$. We use the Nash solution in Section VI.

(5b) $$V^2(y_1,y_2) = F^2\big((1-\gamma(y_1,y_2))T, L_2-y_2\big).$$

Under reasonable conditions a pure strategy equilibrium exists (please see Theorem 2 in Appendix).[10] Although uniqueness and some characterization results in Proposition 1 cannot be guaranteed without additional structure, the result below is akin to Proposition 1(a).

Proposition 2: *Assume* $\gamma=g(p)$ *where* $g'(p) > 0$, p *satisfies* (A1), $p_{11} \le 0$, *and consider an equilibrium* $(\tilde{y}_1,\tilde{y}_2) > (0,0)$. *Then*

$$\tilde{y}_1 > \tilde{y}_2 \text{ if and only if } \tilde{F}^1_t/\tilde{F}^1_x > \tilde{F}^2_t/\tilde{F}^2_x.$$

Utilizing the logic of Proposition 1 in Section II, it can be shown that under the Cobb-Douglas specifications in (3) we will have:[11]

(a) If $L_1=L_2$ then $\tilde{y}_1>\tilde{y}_2$ if and only if $\alpha>\beta$ (or, *the agent who values the contestable resource more highly invests more in arms*).

(b) If $\alpha=\beta$ then $\tilde{y}_1>\tilde{y}_2$ if and only if $L_1>L_2$ (other things equal, *the agent with the largest endowment will invest more in arms*).

Finally, what if the agents are *ex ante* unsure about the rule of division or about whether settlement will take place at all? One way to think about this case is for the agents to have common priors about the likelihood of employing different rules of division or about the likelihood of winner-take- all conflict. For example, letting $V^1(\gamma_j)$ be the settlement payoff of agent 1 when rule γ_j is employed and denoting by q_j the probability of employing this rule, the payoff function $\overline{V}^1 \equiv \sum_j q_j V^1(\gamma_j)$ $(\sum_j q_j=1)$ could be used to handle the problem of uncertainty over the division rule; the payoff function of agent 2 would be similarly defined. As long as each of the division rules γ_j satisfies (A1′), a pure strategy equilibrium will exist and it is then possible to study the implications of this type of uncertainty.

V. Settlement II: Contracting and Allowing for Trade

Although for any given arms allocation there are divisions of the contestable resource which result in Pareto superior allocations to those under conflict, as discussed in Section III there may still be room for improving the outcome for both parties. If x_1 and x_2 were denominated in the same units, the two parties could in general improve upon the equilibrium allocation resulting in the previous subsection (which is $(\gamma(\tilde{y}_1,\tilde{y}_2)T,\tilde{x}_1)$ for agent 1 and $((1-\gamma(\tilde{y}_1,\tilde{y}_2))T,\tilde{x}_2)$ for agent 2 with $x_i=L_i-y_i$, $i=1,2$) by redividing the contestable resource and the agent getting a share smaller than the equilibrium just examined receiving as compensation some of the other agent's x good.

For simplicity, henceforth we employ the following specialization of (B):

(B′)
$$F^1(t,x) = F^2(t,x) = F(t,x) \quad \forall (t,x);$$
$F(t,x)$ is linearly homogeneous and satisfies (B).

Under (B′) the two agents have identical linearly homogeneous production functions (and identical input and final good). Then, for any given T, x_1, and x_2, there is a total product which equals $F(T,x_1+x_2)$. And any Pareto optimal allocation can be represented by a number $\lambda\in[0,1]$ such that the payoff of agent 1 is $\lambda F(T,x_1+x_2)$ and the payoff of agent 2 is $(1-\lambda)F(T,x_1+x_2)$. Note that, by the linear homogeneity of F, these two payoffs are equal to $F(\lambda T,\lambda(x_1+x_2))$ and $F((1-\lambda)T,(1-\lambda)(x_1+x_2))$, respectively. Pareto optimality necessitates that the two inputs are used in the

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[10] The counterpart to (A2) is

(A2′) $$\gamma_{11} \equiv \partial^2\gamma/\partial y_1^2 \le 0 \quad \text{and} \quad -\gamma_{22} \equiv \partial^2\gamma/\partial y_2^2 \le 0$$

(each agent's share is concave in his or her own strategy) which, along with (A1) is sufficient for existence of equilibrium. The payoff functions considered here are different from those in (3) and the structure of $\gamma(y_1,y_2)$ need not coincide with that of $p(y_1,y_2)$.

[11] Note that, since the sharing function γ is not necessarily symmetric, having more arms than your opponent here does not necessarily guarantee a bigger share of the contestable resource, although for the cases we just considered we would expect this to be the norm.

ratio of $T/(x_1+x_2)$.[12]

We suppose that for each combination of arms, (y_1,y_2), there is a unique division of total product with agent 1 receiving a $\lambda(y_1,y_2)$ share and agent 2 receiving a $1-\lambda(y_1,y_2)$ share. Then, the payoff functions can be expressed as

(6a) $$W^1(y_1,y_2) = \lambda(y_1,y_2)F(T,L_1-y_1+L_2-y_2)$$

(6b) $$W^2(y_1,y_2) = (1-\lambda(y_1,y_2))F(T,L_1-y_1+L_2-y_2).$$

A pure-strategy equilibrium exists under reasonable conditions (please see Theorem 3 in the Appendix). We have not discussed thus far how the function $\lambda(y_1,y_2)$ could be generated. The simple dependence on the arms investments of the two agents may yield more complicated dependencies on the disagreements payoffs in (1) and the payoff (or, utility) possibilities set generated by each pair (y_1,y_2). Given that for any given choice of arms the resultant production possibilities frontier is by (B′) linear, a reasonable trading rule is the equal division of the surplus, again with the payoffs in (1) as the disagreement utilities.[13] Equal division of the surplus implies the following trading rule:

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[12] Under (B′) we can also provide an alternative interpretation of trading. Instead of trading taking place in T and x, trading can take place in x and the final good. For example, after dividing T, the agent with the highest proportion of x relative to T will have an incentive to "import" some of the other agent's final good, in exchange for some exports of its relatively abundant x.

[13] Because of the linearity of the Pareto frontier this rule coincides with any symmetric bargaining solution, including the Nash bargaining solution. The use of an axiomatic bargaining solution within a noncooperative is not new practice (see e.g., Grossman and Hart, 1986).

In the earlier version of this paper, we examined two additional rules. The rather ad hoc rule whereby $\lambda(y_1,y_2) = p(y_1,y_2)$, and the rule according to which the agents, after agreeing on a division of T according to some rule $\gamma(y_1,y_2)$, engage in competitive trade. With the Cobb-Douglas function in (3) the latter rule reduces to $\lambda = (1-\alpha)x_1/(x_1+x_2) + \alpha\gamma(y_1,y_2)$, or that agent 1's share of final output is a convex combination of the shares of x and T he/she holds, with the weights being determined by the elasticity parameter α in the Cobb-Douglas function. We use this rule and $\gamma(y_1,y_2) = p(y_1,y_2)$ in Skaperdas and Syropoulos (1994).

(7) $$\lambda = \frac{F(T,x_1+x_2)+pF(T,x_1)-(1-p)F(T,x_2)}{2F(T,x_1+x_2)} = \frac{1}{2} + \frac{pF(T,x_1)-(1-p)F(T,x_2)}{2F(T,x_1+x_2)}.$$

Since $p = p(y_1,y_2)$ and $x_i=L_i-y_i$, λ naturally is a function of (y_1,y_2). The second expression clarifies that the agent with the higher disagreement payoff also receives more than one-half of the total utility. The payoff functions in this case are:

(8a) $$W^1(y_1,y_2) = \frac{1}{2}\Big[F(T,x_1+x_2) + pF(T,x_1) - (1-p)F(T,x_2)\Big]$$

(8b) $$W^2(y_1,y_2) = \frac{1}{2}\Big[F(T,x_1+x_2) - pF(T,x_1) + (1-p)F(T,x_2)\Big].$$

Proposition 3: *Suppose the surplus is equally divided and assume* (A1), $p_{11} \leq 0$, *and* (B′). *Then at any equilibrium the following statements are equivalent:*

(a) $L_1 > L_2$; *(b)* $\tilde{y}_1 > \tilde{y}_2$; *(c)* $\tilde{\lambda} > \frac{1}{2}$.

These properties as qualitatively similar to those we obtained for winner-take-all conflict (Proposition 1a) and Settlement I (Proposition 2): The agent with the larger endowment chooses more arms than his opponent in equilibrium and receives a higher share of total output.[14] Therefore, and once again in contrast to models of conflict and rent-seeking without complementarities, agents who have more initial resource endowments have an advantage regardless of the regime they happen to implement.

VI. A Comparison of Rules and Regimes: Could Trade be Undesirable?

We have thus far examined each regime – Conflict, Settlement I, or Settlement II –

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[14] Under the Cobb-Douglas function in (3), the statements in Proposition 3 are also equivalent to $\tilde{\lambda} < \tilde{x}_1/(\tilde{x}_1+\tilde{x}_2)$, where $\tilde{x}_i=L_i-\tilde{y}_i$ is the quantity of x held by agent *i* *before* the final exchange occurs. The inequality $\tilde{\lambda} < \tilde{x}_1/(\tilde{x}_1+\tilde{x}_2)$ means that agent 1, the one with a larger endowment and more power, actually gives up some of his $\tilde{x}_1$ to agent 2 in exchange for some of t or (according to the alternative interpretation) in exchange for the final output.

separately. Although we have shown the existence of some regularities across the three regimes, the equilibrium level of arming and of welfare can be expected to vary across the three regimes because incentives differ. To highlight such differences, in this section we provide several comparisons across the regimes. Our purpose is not generality but rather to illustrate and discuss possibilities that cannot occur when property is secure. In particular, we show how contracting without trading (i.e., Settlement I) could be *ex ante* preferable to contracting with trading (i.e., Settlement II) by both or just one of the parties, and then we discuss some possible implications of this property. Another way to see the exercise we undertake here is to think of it as one that explores the circumstances under which one of the regimes has better stability properties than the other two and is therefore more likely to be the one that prevails in the interactions among the adversaries.

A. Identical Parties

We first examine the case with two identical agents. Both agents have identical Cobb-Douglas technologies (i.e., $\beta=\alpha$ in (3)) and equal endowments ($L_1=L_2=L$). We employ the contest success function $p = y_1/(y_1+y_2)$, the functional form often used in the rent-seeking literature. For Settlement I we suppose that the agents divide the contested resource according to the Nash bargaining solution, the most commonly used bargaining solution. For Settlement II we suppose that the surplus is divided equally.[15] The payoffs for agent 1 under conflict (U^1), Settlement I (V^1), and Settlement II (W^1) are reproduced from (1), (5) and (6) below for convenience (the payoffs for agent 2 are similarly defined):

(9a) $$U^1 = pT^{\alpha}(L_1-y_1)^{1-\alpha}$$

(9b) $$V^1 = (\gamma T)^{\alpha}(L_1-y_1)^{1-\alpha}$$

[15] In both Settlement I and Settlement II the disagreement payoffs are those of conflict in (1).

(9c) $$W^1 = \lambda T^{\alpha}(L_1-y_1+L_2-y_2)^{1-\alpha}$$

where

$$\gamma \text{ solves } \left(\frac{1-\gamma}{\gamma}\right)^{1-\alpha} = \frac{(1-\gamma)^{\alpha} - (1-p)}{\gamma^{\alpha} - p} \quad \text{(as in footnote 9)}$$

$$\lambda = \frac{1}{2} + \frac{p(L_1-y_1)^{1-\alpha} - (1-p)(L_2-y_2)^{1-\alpha}}{2(L_1-y_1+L_2-y_2)^{1-\alpha}} \quad \text{as in (7).}$$

The (unique symmetric) equilibrium arms expenditures for the three regimes (Conflict, Settlement I, and Settlement II), denoted by y_C, y_I, and y_{II}, can be shown to equal:

(10)
$$y_C = L/(3-2\alpha)$$
$$y_I = \alpha L/\left[2(2^{1-\alpha}-1+\alpha)(1-\alpha)+\alpha\right]$$
$$y_{II} = L/\left[(1+2^{1-\alpha})(1-\alpha)+1\right].$$

These quantities have the following property for all α and L:

$$y_C > y_{II} > y_I.$$

The fact that arming is highest under conflict does not appear surprising; under conflict the only means by which one has hope of winning the contested resource is arming and, therefore, the competing parties can be expected to go all-out to capture that resource. What appears surprising, however, is that arming is higher under Settlement II than under Settlement I. We will have to say more on this seeming paradox, but for now we offer the following preliminary intuitive rationale. By comparing the form of the payoff functions under Settlement I in (9b) and under Settlement II in (9c), we can see that the problem of Settlement II appears as one in which the parties are competing for a "pie" which consists of the total final product (that is, $T^{\alpha}(L_1-y_1+L_2-y_2)^{1-\alpha}$), whereas the object of bargaining under Settlement I is just the contested resource (plus each party's own productive input, that is,

$T^{\alpha}(L_1-y_1)^{1-\alpha}$) without having to worry about any additional gains from trade.[16] Therefore, ignoring any differences in the way the sharing of these pies takes place, we would expect more arming when the pie is bigger, that is, under Settlement II. Of course the sharing functions are different under the two regimes, thus possibly providing the opposite incentives for arming but the "bigger pie" intuition is the one that basically drives greater arming under Settlement II.

For a given level of arming, welfare is highest under Settlement II since both division of the contested resource and trade take place under that regime. With arming though being higher under Settlement II, the possibility exists that *equilibrium welfare* is lower than that under Settlement I. In fact with identical agents under Settlement II there are no gains from trade to be realized in equilibrium since the two parties divide the contested resource in half under both Settlement I and II and do not trade under the latter. But since arming is higher under Settlement II, the available x (= $L-y_{II}$) must be lower than that under Settlement I and, therefore, equilibrium welfare must be lower under Settlement II. By substituting the values in (10) into (9) it is straightforward to confirm that the equilibrium payoffs of the two identical parties are highest under Settlement I, next highest under Settlement II, and lowest under conflict. Since once the parties have chosen their arms they would prefer to divide the resource and trade (and thus follow Settlement II), to avoid the higher arming and the lower welfare of this regime the two parties would have an incentive to *ex ante* commit not to trade.

B. Different Parties

When the two parties differ in their initial endowments it is not possible to derive analytical expressions for equilibrium arming and welfare under (9), but it is

[16] An additional feature of the "bigger pie" effect is the lower marginal productivity of x and therefore the lower opportunity cost of arming under the bigger pie.

possible to do so numerically. We present some of the information we obtained numerically in Figures 3 and 4.

Figure 3 about here

Figure 3 shows that when the two parties are sufficiently similar in terms of their initial endowments we have the same qualitative outcome as when they are identical: both parties ex ante prefer not to trade, that is their equilibrium payoffs under Settlement I are higher than those under Settlement II. Whereas the bigger pie under Settlement II encourages more arming, the similarity of the parties does not make for large enough gains from trade to counteract this higher arming.

When the two parties though are very different - one has a much higher initial endowment than the other - Settlement II is ex ante preferable by both of them. The gains from trade in such a case are maximal and can counteract the higher arming that comes from the "bigger pie" effect. In the intermediate cases when the parties are different but not too different, the smaller party prefers trade but the larger one does not. Apparently, the smaller party reaps relatively higher gains from trade, whereas the larger party does not receive enough of them to compensate for the higher arming under Settlement II.

Figure 4 about here

In Figure 3 the parameter α, the elasticity of output with respect to the contested resource, equals 0.9. Figure 4 shows how the three types of regions vary as α as well as the distribution of initial endowments vary, but for a given total endowment L for the two parties (set equal to 100). (Thus Figure 4 includes the set of points in Figure 3 that are only along the diagonal dotted line.) It can be immediately seen that as α becomes smaller the region in which both parties prefer not to trade becomes larger. For small enough α (approximately less than 0.85), the region in which both parties would prefer to trade disappears and, therefore, under that much total endowment and regardless of its distribution at least one party would ex ante prefer not to trade.[17] Again the best way to understand this tendency of trade becoming less preferable as the contested resource becomes less important (that is, as α becomes smaller), is to use the "pie" intuition. A decrease in α means that the pie to be divided under Settlement I, which consists primarily of the contested resource, becomes smaller relative to the bigger pie under Settlement II since the elasticity associated with the former becomes smaller. This increasing dissimilarity in pies implies increased arming under Settlement II relative to Settlement I, a fact which necessitates an increased dissimilarity between the parties - and hence higher gains from trade - to bring about a higher equilibrium welfare under Settlement II for even just one of the parties.

Overall, other things equal, Settlement II and trade is *ex ante* preferable to Settlement I (a) the greater is the dissimilarity of the parties, (b) the greater is the sum of their endowments, and (c) the more important is the contested resource (and the less important is the other productive input) in producing the final good. This last effect means that there is a good chance of trade being preferable in places like Eastern Europe where insecure resources are central to the functioning of the economy, especially relative to the prospective gains from trade.

Given that in many instances one or both parties would *ex ante* prefer not to trade, there would exist incentives to commit not to trade (since *ex post*, once the parties are armed, they would prefer to trade). Probably the simplest commitment mechanism is the presence, or the imposition by the interested party, of trade restrictions that are effectively difficult to circumvent. Therefore insecure ownership may have been an important reason for the imposition of trade restrictions

[17] Note that for higher total endowments there would exist sufficiently extreme distributions for which both parties could prefer Settlement II even for low αs. This can be visualized by extrapolating the two lines at the top of Figure 4.

in the past and possibly may still be one in the present.[18] Of course, as indicated by Bhagwati (1971), other types of (factor market) distortions can lead to the same result but insecure ownership is an empirically important distortion which apparently has not been explored.[19]

Regardless of the particulars, the exercise we have undertaken in this section indicates how one of the three possible regimes - in this case either Settlement I or Settlement II - could emerge as the stable regime. While we have not shown the conflict regime to be preferable by one or both parties in this example, under different conditions (when trading takes place under competitive conditions, instead of following a split-the-surplus rule we have followed here, shown in Skaperdas and Syropoulos, 1994) this outcome is possible. We are far from claiming, however, that this is a primary method the different regimes are selected in actuality. History,

[18] One example of blanket trade restrictions which has been difficult to understand and our approach could possibly inform is the prohibition of all trade by Chinese subjects instituted by the Ming dynasty in the fifteenth century and which lasted for centuries. (See, e.g., Chaudhuri (1985, Ch.2) or Kennedy (1989, Ch.1).) Significantly, the prohibition followed in the heels of several successful naval expeditions by a Chinese naval force which went as far away as Africa and the Red Sea; the naval force was dissolved about the same time as the trading prohibition took effect. In the absence of a trading prohibition the Chinese bureaucrats probably felt they would be compelled to maintain an expensive navy that could not be justified by the possibly large but uncertain trading gains. (The loss of control by the bureaucrats that could occur if trade were to truly take off is another explanation that has been offered for the prohibition, but which can be complementary to ours.) Note also that in our example a large party, like China, is more likely to prefer such a blanket trade restriction.

Similar restrictions have been imposed throughout history not necessarily on every subject within a country but on selected groups of individuals. In France almost up to the French Revolution (Schama, 1989, p.118) there was a prohibition on all members of the French nobility to participate in commercial transactions other than on their own account. The original rationale for such a prohibition is unclear, but given that the nobles were the traditional warrior class it could be argued that the prohibition reduced the "pie" they could lay claims on and therefore it lessened the temptation of the French nobles to use their military capability domestically (and save it for purposes that better suited the king).

[19] Seniority-based promotions and other rigid rules in hierarchical organizations can similarly be explained by the reduction in influence activities (i.e., rent-seeking within organizations) that such rules can bring compared to when such rules are absent and more flexibility and implicit trades can occur between members of the organization (Milgrom, 1988).

conventions, and the personal experiences of the adversaries can be powerful determinants of how claims to insecure resources are eventually settled. In some societies backing down and dividing disputed property - and, worse still, trading afterward with one's adversaries - may simply be unacceptable practice, while in others that would be normal.

VII. Concluding Remarks

Previous work on property rights has paid almost exclusive attention to the overexploitation problems of common pool resources under open access. Many economic resources without secure property, however, do not share this characteristic; when no one, for instance, has secure possession of some resources, no one can exploit it. Moreover, even common pool and open access resources can suffer from the problems we have sought to identify here. We have emphasized the role of distributional conflict for capturing an insecure resource and analytically distinguished among different types of costs of insecure property: the costs of potential or actual use of force; costs associated with the uncertainty about who will capture the contested resource; and costs associated with the possible lack of tradeability of the insecure resource as well as of other commodities.

The magnitude of each of these types of costs varies with the expectations the adversaries have when they make choices between production and arming and the conventions they follow. Though the expectation of settlement and trading can in principle eliminate two types of these costs (uncertainty and lack of tradeability), the costs of arming can be high enough under such a convention so as to outweigh ex ante the benefits of tradeability. This occurs, for instance, when the adversaries are not sufficiently different and the potential benefits to trade are small.

We have hinted an avenue through which conventions could develop - through their greater stability when compared to a limited set of alternatives. But there exist

many other ways that conventions develop for settling claims to property across different societies and economies. There are also conventions that are thought up that do not neatly fit to any of those we have examined; for example settling a land dispute between two tribes through ritualistic duel of the strongest warriors in each tribe. Whatever convention is given time to develop, however, even in an anarchic environment it must have some robustness to different types of disputes. The less robust it is, the more likely winner-take-all conflict seems as the default convention.

Secure property rights that require minimal enforcement (which we can operationalize in our framework with γ or λ functions that are rather unresponsive to arming) could develop either through a contractarian process among essentially equal partners or through the capture of the monopoly of force - of the state - by one dominant group. Although the relative autonomy of modern states makes them appear to conform to the contractarian paradigm, their origins can be arguably located in the use of force.[20] Some of the consistencies we have found across the different regimes we have examined - in particular, the fact that the better endowed adversaries always do better - hint at those who are more likely to develop the monopoly of force and eventually develop more secure property rights.

[20] See Tilly (1985). Section I in Findlay (1990) also provides an illuminating survey of the evolution of the modern state.

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APPENDIX

Theorem 1:

(a) Assume (A1), (A2) *and* (B). *Then a pure-strategy equilibrium exists.*

(b) Assume (A1)-(A3) *and* (B). *Then the pure-strategy equilibrium is unique.*

Proof: Part (a): We will show that each agent's payoff function, defined in (1), is quasiconcave in the agent's own strategy, y_1 for agent 1 and y_2 for agent 2. Since the strategies are one dimensional, it not hard to show (see, e.g., Lemma A2 in Skaperdas, 1992) that quasiconcavity of U^1 in y_1 is implied by the following property:

(A.1) $$U^1_{11} < 0 \text{ if } U^1_1 \le 0 \quad (i=1,2).$$

For specificity, consider $i=1$. Assume

(A.2) $$U^1_1 = p_1F^1 - pF^1_x \le 0$$

which implies $F^1 \le pF^1_x/p_1$. Using this property in the second derivative yields:

(A.3) $$U^1_{11} = p_{11}F^1 - 2p_1F^1_x + pF^1_{xx} \le p_{11}pF^1_x/p_1 - 2p_1F^1_x + pF^1_{xx}.$$

By using (A2) in the first term of the right-hand-side we obtain

(A.3′) $$U^1_{11} \le p_1F^1_x - 2p_1F^1_x + pF^1_{xx} = - p_1F^1_x + pF^1_{xx}$$

which, by (A1) and (B), is negative. Thus, (A.1) is satisfied for $i=1$ and agent 1's payoff function is quasiconcave in her strategy. The proof for $i=2$ follows exactly the same steps.

Part (b): By arguments similar to those in the proof of Theorem 2 in Skaperdas (1992), to prove uniqueness of equilibrium it is sufficient to show that

(A.4) $$r_1'(\tilde{y}_2)r_2'(\tilde{y}_1) < 1$$

where $r_1(\cdot)$ denotes the best response function of agent 1 and $(\tilde{y}_1,\tilde{y}_2)$ is any equilibrium point. We just examine interior equilibria (the cases with corner solutions can be shown to be stable by an argument in Lemma A5, Skaperdas, 1992).

Then, (A.4) is equivalent to:

(A.4′) $$(U^1_{12}U^2_{21})/(U^1_{11}U^2_{22}) < 1$$

where all functions are evaluated at the equilibrium point under consideration (to avoid cluttering, we omit the tildes). By (2) the following properties hold at the equilibrium point:

(A.5a) $$F^1 = pF^1_x/p_1$$

(A.5b) $$F^2 = (1-p)F^2_x/(-p_2).$$

Substituting (A.5a) in (A.3) leads to

(A.3″) $$U^1_{11} = (p_{11}p - 2p_1^2)F^1_x/p_1 + pF^1_{xx}$$

which by (A1) and (A2) implies

(A.6) $$U^1_{11} < -p_1F^1_x.$$

Using a similar argument, we can also obtain

(A.7) $$U^2_{22} < p_2F^2_x.$$

By (A.6) and (A.7) we then have

(A.8) $$U^1_{11}U^2_{22} > -p_1p_2F^1_xF^2_x.$$

Differentiation of (A.2) and application of (A.5a) also yields:

(A.9) $$U^1_{12} = p_{12}F^1 - p_2F^1_x = F^1_x(p_{12}p - p_2p_1)/p_1.$$

It is straightforward, but tedious, to show that under (A3) we have:

$$p_{12}p = (1-2p)p_1p_2/(1-p).$$

Substituting this expression into (A.9) and manipulating the resulting expression yields

(A.10) $$U^1_{12} = F^1_x(-p_2)p/(1-p).$$

A similar argument can establish the corresponding expression for agent 2's payoff cross derivative

(A.11) $$U^2_{21} = F^2_xp_1(1-p)/p.$$

(A.10) and (A.11) then yield

$$U^1_{12}U^2_{21} = -p_1p_2F^1_xF^2_x$$

which along with (A.8) readily imply (A.4′). ∎

Proof of Proposition 1: Consider an equilibrium point $(\tilde{y}_1,\tilde{y}_2) > (0,0)$.

Part (a): Rearrange (2a) and (2b) to obtain

(A.12) $$\frac{\tilde{F}^1_x/\tilde{F}^1}{\tilde{F}^2_x/\tilde{F}^2} = -\frac{\tilde{p}_1(1-\tilde{p})}{\tilde{p}_2\tilde{p}}.$$

By the argument in Skaperdas (1992, Lemma A5), conditions (A1) and (A2) ensure that the right-hand-side (RHS) of the above expression is less than unity if and only if $p(\tilde{y}_1,\tilde{y}_2) > \frac{1}{2}$ which, by (A1), is true if (and only if) $\tilde{y}_1 > \tilde{y}_2$.

Parts (b) and (c): Differentiate (2a) and (2b) totally at the equilibrium point to obtain

$$\begin{bmatrix} d\tilde{U}^1_1 \\ d\tilde{U}^2_2 \end{bmatrix} = \begin{bmatrix} \tilde{U}^1_{11} & \tilde{U}^1_{12} \\ \tilde{U}^2_{21} & \tilde{U}^2_{22} \end{bmatrix} \begin{bmatrix} d\tilde{y}_1 \\ d\tilde{y}_2 \end{bmatrix} + \begin{bmatrix} \tilde{U}^1_{1T} \\ \tilde{U}^2_{2T} \end{bmatrix} dT + \begin{bmatrix} \tilde{U}^1_{1L_1} \\ 0 \end{bmatrix} dL_1 + \begin{bmatrix} 0 \\ \tilde{U}^2_{2L_2} \end{bmatrix} dL_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

Solving the above system of equations for $d\tilde{y}_1$ and $d\tilde{y}_2$ yields

(A.13) $$\begin{bmatrix} d\tilde{y}_1 \\ d\tilde{y}_2 \end{bmatrix} = -\left(\frac{1}{\Delta}\right)\left(\begin{bmatrix} (\tilde{U}^2_{22}\tilde{U}^1_{1T} - \tilde{U}^1_{12}\tilde{U}^2_{2T}) \\ (\tilde{U}^1_{11}\tilde{U}^2_{2T} - \tilde{U}^2_{21}\tilde{U}^1_{1T}) \end{bmatrix} dT + \begin{bmatrix} \tilde{U}^2_{22} \\ -\tilde{U}^2_{21} \end{bmatrix} \tilde{U}^1_{1L_1} dL_1 + \begin{bmatrix} -\tilde{U}^1_{12} \\ \tilde{U}^1_{11} \end{bmatrix} \tilde{U}^2_{2L_2} dL_2 \right)$$

where $\Delta \equiv \tilde{U}^1_{11}\tilde{U}^2_{22} - \tilde{U}^1_{12}\tilde{U}^2_{21} > 0$ from (A.4′), $\tilde{U}^1_{11} < 0$ $(i=1,2)$ from (A.6) and (A.7), and $\tilde{U}^1_{12} > 0$ and $\tilde{U}^2_{21} > 0$ from (A.10) and (A.11). Parts (b) and (c) now follow by recalling that $\sigma_1 \equiv (F^1_xF^1_t)/(F^1F^1_{xt})$ $(i=1,2)$ and observing that

(A.14a) $\quad \tilde{U}^1_{1T} = \tilde{p}\tilde{F}^1_{xt}(\tilde{\sigma}_1 - 1); \qquad \tilde{U}^2_{2T} = (1-\tilde{p})\tilde{F}^2_{xt}(\tilde{\sigma}_2 - 1);$

(A.14b) $\quad \tilde{U}^1_{1L_1} = \tilde{p}_1\tilde{F}^1_x - \tilde{p}\tilde{F}^1_{xx} > 0; \qquad \tilde{U}^2_{2L_2} = -\tilde{p}_2\tilde{F}^2_x - (1-\tilde{p})\tilde{F}^2_{xx} > 0$

while, by (B), $\tilde{F}^i_{xt} > 0$ and $\tilde{F}^i_{xx} < 0$ for $i=1,2$. ∎

Theorem 2: *Assume* (A1′), (A2′), *and* (B) *under the payoff functions in* (5). *Then a pure-strategy equilibrium exists.*

Proof: We just show that V^1 in (5a) is concave in y_1 (i.e., $V^1_{11} \equiv \partial^2 V^1/\partial y_1^2 \le 0$). Differentiating V^1 twice with respect to y_1 yields

(A.15) $\quad V^1_{11} = (\gamma_1 T)^2 F^1_{tt} - 2\gamma_1 T F^1_{tx} + F^1_{xx} + \gamma_{11} T F^1_t.$

By (B) and (A1′) all the terms (except the last) in the RHS of the above expression are negative. By (B) and (A2′) the last term is nonpositive. Consequently, the entire expression must be negative. ∎

Lemma A: *(Used in the proofs of several propositions.) Assume* (A1), $p_{11} \le 0$, *and* $p_{12}(w,z) \ne 0$ *if* $w \ne z$. *Then*

$$p(y_1,y_2) > \frac{1}{2} \Leftrightarrow p_1(y_1,y_2) < -p_2(y_1,y_2) \quad \forall\ (y_1,y_2).$$

Proof: (⇐) Suppose $p(y_1,y_2) \ge \frac{1}{2}$ ($\Leftrightarrow y_1 > y_2$). Then by $p_{11} \le 0$ we have

(A.16a) $\quad p_1(y_1,y_2) \le p_1(y_2,y_2)$

(A.16b) $\quad -p_2(y_1,y_2) \le -p_2(y_1,y_1).$

Given that $p_{12}(w,z) \ne 0$ when $w \ne z$, and since $y_1 > y_2$, there are two cases to examine:

<u>CASE 1</u>: $\quad p_{12}(y_1,y_2) > 0.$

Given $y_1 > y_2$ we then have $p_2(y_1,y_2) < p_2(y_2,y_2)$ which implies $-p_2(y_1,y_2) > -p_2(y_2,y_2)$. Since $-p_2(y_2,y_2) < p_1(y_2,y_2)$, by (A.16a) the desired result $[-p_2(y_1,y_2) < p_1(y_1,y_2)]$ follows through.

<u>CASE 2</u>: $\quad p_{12}(y_1,y_2) < 0.$

This property (again, given $y_1 > y_2$) implies $p_1(y_1,y_2) < p_1(y_1,y_1) = -p_2(y_1,y_1)$

which, in turn, by (A.16b) is less than or equal to $-p_2(y_1,y_2)$, or that $-p_2(y_1,y_2) < p_1(y_1,y_2)$, again as required by the Lemma.

(⇒) Using similar steps to those we just used it can be shown that $p(y_1,y_2) \le \frac{1}{2}$ implies $p_1(y_1,y_2) \ge -p_2(y_1,y_2)$. ∎

Proof of Proposition 2: Consider such an equilibrium with $(\tilde{y}_1,\tilde{y}_2) > (0,0)$. Then, the following conditions must hold true at the equilibrium point, as can be verified by differentiating (6a) and (6b) appropriately:

(A.17a) $\quad \tilde{V}^1_1 = g'(\tilde{p})\tilde{p}_1 T\tilde{F}^1_t - \tilde{F}^1_x = 0$

(A.17b) $\quad \tilde{V}^2_2 = -g'(\tilde{p})\tilde{p}_2 T\tilde{F}^2_t - \tilde{F}^2_x = 0.$

These two expressions imply

(A.18) $$\frac{-\tilde{p}_2}{\tilde{p}_1} = \frac{\tilde{F}^1_t/\tilde{F}^1_x}{\tilde{F}^2_t/\tilde{F}^2_x}.$$

By Lemma A, the fact that $p_{11} \le 0$ and a minor condition, $p > \frac{1}{2}$ if and only if $p_1 < -p_2$. Consequently having $\tilde{y}_1 > \tilde{y}_2$ ($\Leftrightarrow \tilde{p} > \frac{1}{2}$) is equivalent to the LHS of (A.18) being greater than 1, which in equilibrium is equivalent to the RHS being greater than one, or $\tilde{F}^1_t/\tilde{F}^1_x > \tilde{F}^2_t/\tilde{F}^2_x$, as required. ∎

The sharing function $\lambda(y_1,y_2)$ satisfies the following properties:

(A1″) $\quad \lambda(y_1,y_2) \in (0,1)$ is differentiable; $\lambda_1 \equiv \partial\lambda/\partial y_1 > 0$, $\lambda_2 \equiv \partial\lambda/\partial y_2 < 0$;

(A2″) $\quad \lambda_{11} \le \lambda_1^2$ (and, by symmetry, $-\lambda_{22}(1-\lambda) \le \lambda_2^2$).

Condition (A1″) is similar to (A1′), which governs the sharing function $\gamma(y_1,y_2)$ used under Settlement I. Condition (A2″), however, is similar to (A2), not the stronger (A2′) we used in Settlement I. This is due to the similarity of the payoff functions in (6) with those under the winner-take-all case in (1). Note though that

$p(y_1,y_2)$ is a probability function whereas $\lambda(y_1,y_2)$ is a deterministic share. Uniqueness of equilibrium is guaranteed under an additive representation of $\lambda(y_1,y_2)$ like the one in (A3), but for all the examples we discuss below (except one) this property is not satisfied.

Theorem 3: *Assume (A1″), (A2″), (B′) under the payoff functions in (6). Then a pure-strategy equilibrium exists.*

Proof: We follow the method used in the proof of Theorem 1, part (a). In particular, we show that each agent's payoff function is quasiconcave in the agent's own strategy which in this case is equivalent to the following counterpart of (A.1):

(A.1′) $\quad W^{i}_{ii} < 0$ if $W^{i}_{i} \le 0$ $(i=1,2)$

We just show this for $i=1$. Using (7a) and rearranging terms it can be shown that $W^1_1 \le 0$ easily implies

$$F \le \lambda F_x/\lambda_1$$

where $F \equiv F(T,x_1+x_2)$. Utilizing this property in the second derivative leads to

(A.3′) $\quad W^1_{11} = \lambda_{11}F - 2\lambda_1 F_x + \lambda F_{xx} \le \lambda_{11}\lambda F_x/\lambda_1 - 2\lambda_1 F_x + \lambda F_{xx}.$

Applying (A2′) in the first term of the RHS of the expression above, we obtain

$$W^1_{11} \le \lambda_1 F_x - 2\lambda_1 F_x + \lambda F_{xx} = -\lambda_1 F_x + \lambda F_{xx}$$

which, by (A1″) and (B) (all F's under (B′) satisfy (B)), is negative. Thus, (A.1′) is satisfied for $i=1$ and agent 1's payoff function is quasiconcave in her strategy. The proof for $i=2$ follows exactly the same steps. ∎

Proof of Proposition 3: Before showing the various equivalences, we have to do some preparatory work. Let $F \equiv F(T,x_1+x_2)$, $F^1 \equiv F(T,x_1)$, and $F^2 \equiv F(T,x_2)$. Differentiating (8a) and (8b) with respect to y_1 and y_2, setting them equal to zero at an interior equilibrium, and rearranging terms yields:

(A.20a) $\quad \tilde p_1(\tilde F^1+\tilde F^2) - \tilde p\tilde F^1_x = \tilde F_x$

(A.20b) $\quad -\tilde p_2(\tilde F^1+\tilde F^2) - (1-\tilde p)\tilde F^2_x = \tilde F_x.$

Since the RHS of the above expressions is the same, the LHS must also be the same. Thus, we have:

(A.21) $\quad \tilde p_1(\tilde F^1+\tilde F^2) - \tilde p\tilde F^1_x = -\tilde p_2(\tilde F^1+\tilde F^2) - (1-\tilde p)\tilde F^2_x.$

[*(b)* ⇒ *(a)*] Assume *(b)* $(\tilde y_1 > \tilde y_2)$ which is equivalent to $\tilde p > \frac{1}{2}$. Since, by assumption, we have $p_{11} \le 0$, Lemma A then implies $\tilde p_1 < -\tilde p_2$. Therefore, we have

$$\tilde p_1(\tilde F^1+\tilde F^2) - \tilde p\tilde F^1_x < -\tilde p_2(\tilde F^1+\tilde F^2) - (1-\tilde p)\tilde F^1_x.$$

From (A.21) we must have $\tilde F^1_x > \tilde F^2_x$ which by (A1) implies that $\tilde x_1 > \tilde x_2$ or

(A.22) $\quad L_1 - \tilde y_1 > L_2 - \tilde y_2.$

Since, by assumption, $\tilde y_1 > \tilde y_2$ this last inequality implies $L_1 > L_2$.

[*(a)* ⇒ *(b)*] This is the same as not*(b)* ⇒ not*(a)*, or that $\tilde y_1 \le \tilde y_2$ implies $L_1 \le L_2$. Utilizing the above argument (i.e., $\tilde y_1 > \tilde y_2$ implies $L_1 > L_2$) it is not hard to show that $\tilde y_1 = \tilde y_2$ implies $L_1 = L_2$.

[*(b)* ⇒ *(c)*] Assume $\tilde y_1 > \tilde y_2$ which is equivalent to $\tilde p > \frac{1}{2}$. By (A.22) we also have $\tilde x_1 > \tilde x_2$; therefore, $\tilde p F(T,\tilde x_1) > (1-\tilde p)F(T,\tilde x_2)$. By definition

$$\tilde\lambda = \frac{1}{2} + \frac{\tilde p F(T,\tilde x_1) - (1-\tilde p)F(T,\tilde x_2)}{2F(T,\tilde x_1+\tilde x_2)}.$$

Since, as we just established, the numerator of the second term of the above expression is negative it follows that $\tilde\lambda > \frac{1}{2}$, as required.

[*(c)* ⇒ *(b)*] It can be shown via not*(b)* ⇒ not*(c)*. ∎

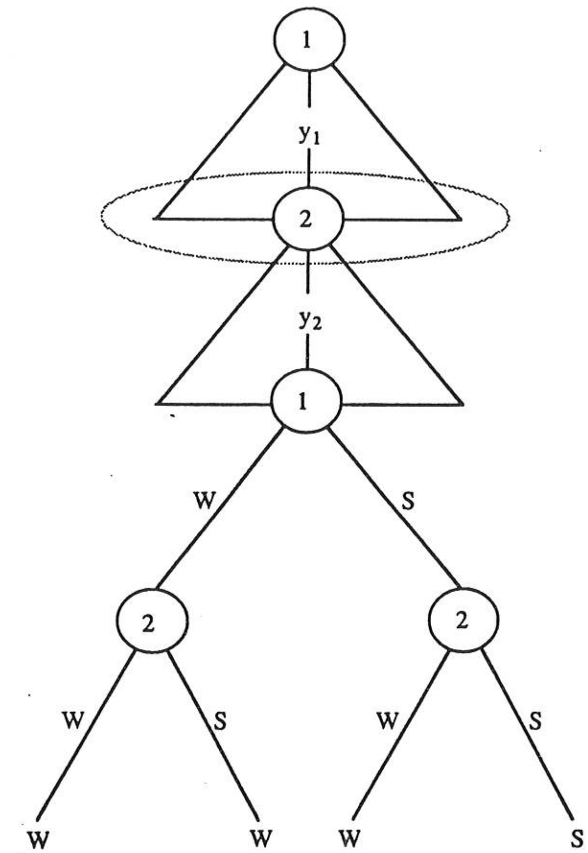

Figure 1

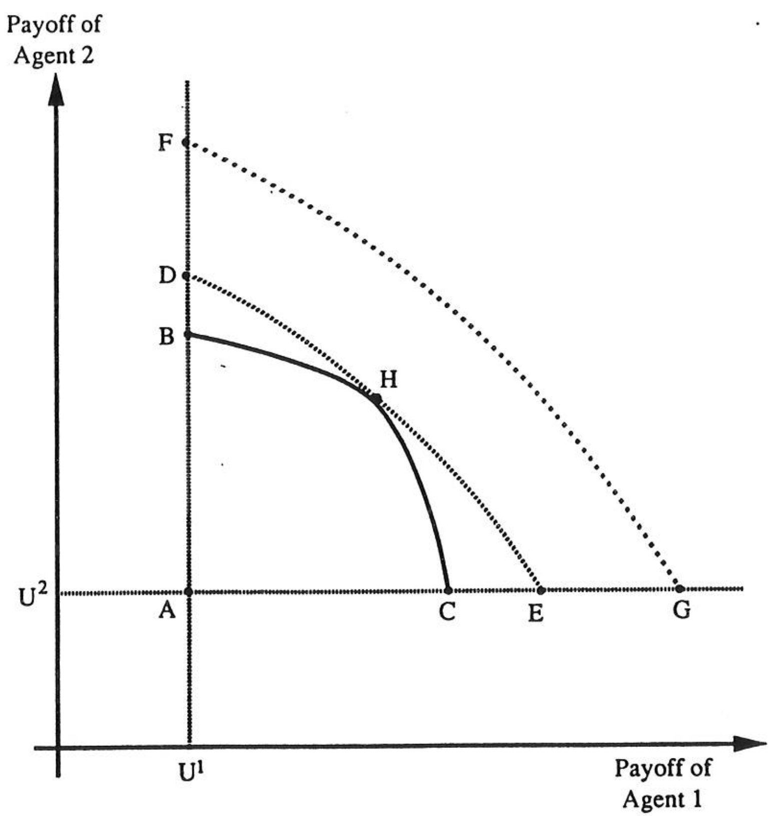

Figure 2

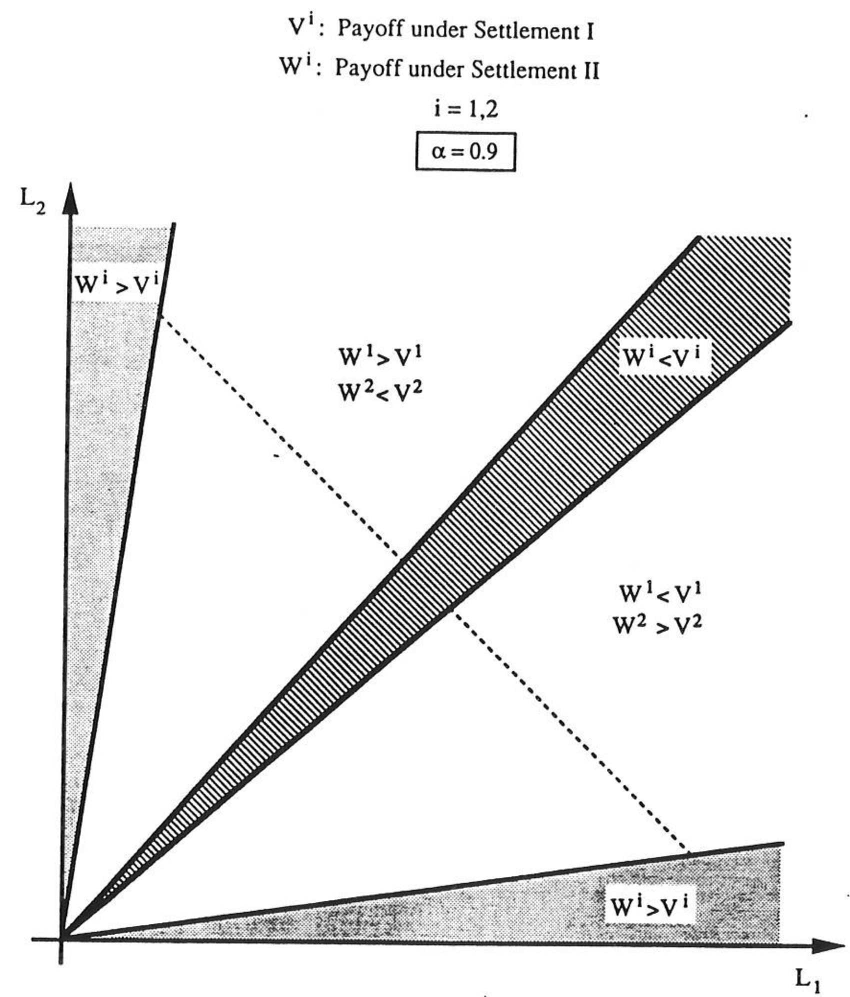

Figure 3

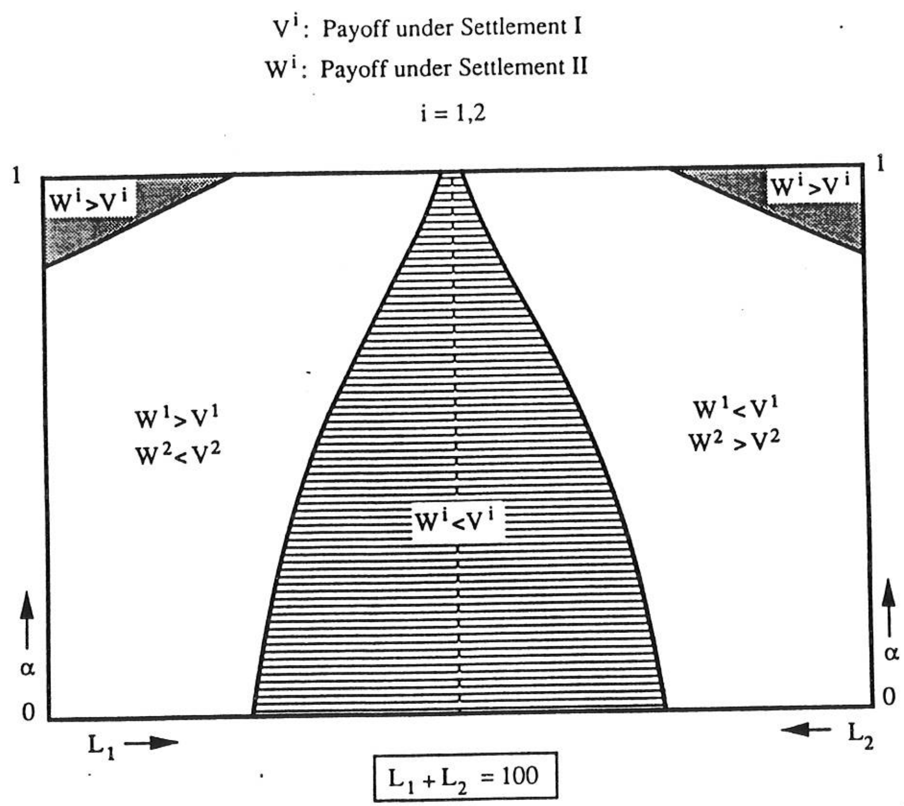

Figure 4

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