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CARROTS, STICKS, AND THE MULTIPLICATION EFFECT

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ABSTRACT

Although a punishment can be applied only once, the threat to punish (also referred to as stick) can be reiterated several times, because when parties obey, the punishment is not applied and thus the threat can be repeated. The same is not possible with promises to reward (also known as carrots), since they need to be carried on every time a party complies, and hence at each round a new reward is needed. We show that the multipliability of sticks has pervasive consequences in economics and law and provides a unified explanation for seemingly unrelated phenomena such as the dynamics of riots and revolutions, the divide-and-conquer strategy, comparative negligence, the anticommons problem, the use of property rules in markets, the most-favored-nation clause, legal restrictions on penalties in employment contracts, and legal aid.

JEL classification: C72, K12, K13, K14, K42.

Keywords: enforcement, comparative negligence, divide-and-conquer, revolutions, legal aid, redistribution in kind.

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1. Introduction

This paper seeks to answer a simple question: can a sanction of \$100 ever lead to a behavioral change of more than \$100? That is, can a principal, who can threaten to apply a sanction that would cost an agent \$100, induce this agent to follow a command or abide by rule that requires an effort to the agent of more than \$100? By the same token, can a reward of \$100 ever incentivize an agent for more than \$100? More generally, is the incentive effect of a sanction limited to its magnitude, or is it possible to multiply the effect of a sanction, so that agents spend more on following the command than the amount of the sanction?

The answer depends on the sign of the sanction.¹ People's conduct may be influenced by means of carrots (promises to reward, e.g., with a bonus, reward, prize or payment) or sticks (threats to punish, e.g., with a fine, damage payment, imprisonment or physical sanction). In this paper, we argue that sticks feature a specific characteristic absent in carrots. Sticks can – under some conditions – be multiplied, that is, the same stick can be applied repeatedly to incentivize the same party in different periods or several parties simultaneously.² On the contrary, a carrot can be applied only once. This peculiar characteristic of sticks is grounded in the fact that if the agent complies, the threat to punish does not need to be carried on and hence can be used to incentivize yet again the same or another agent.³ Quite the opposite, a reward has to be paid to complying agents and hence it is consumed at every use and cannot be recycled.

That the effect of sticks can be multiplied can be illustrated by the following 3 examples.

¹ The attention of modern economics to law enforcement problems dates back to Becker (1968). However, the sign of the sanction – that is, whether enforcement is based on punishments or rewards – has hardly been considered as an important issue for what concerns incentives. Coase (1960) implicitly endorses the view that punishing and rewarding have the same effects; likewise, Coase (1988) makes no distinction between threats to punish and promises to reward. An exception to this trend is provided by the work of Wittman, who focused on the choice between carrots and sticks in different enforcement contexts (see Wittman, 1998, for a synthesis of his studies) and Lazear (1995, 65-69) who do not mention, however, the multiplication effect that we study in this paper. This study is part of a broader research that we are conducting on the use carrots vs. sticks in legal and social enforcement systems (De Geest and Dari-Mattiacci, _____).

² This characteristic has nothing to do with non-rivalry or non-excludability in consumption. Obviously, if a non-rival good (e.g., the possibility to see a video of the last albino gorilla) is used to reward, then the same carrot can be used repeatedly. However, the same would be possible with non-rival punishments (e.g., the sight of a horrific situation). On the contrary, our analysis applies to rival rewards and punishments, that is, to rewards and punishments that can be applied only once, since they are consumed with use. The point we defend and develop in this paper is precisely that, although a punishment can be applied only once, the threat to punish (the stick) can be reiterated, because the punishment is not applied in equilibrium. Under the same conditions, this is not possible with carrots.

³ Multiplication has nothing to do with problems of illicit appropriation, ex post opportunism, or cheating. In our formal analysis and in our examples sanctions are always applied as promised and parties behave according to the

Example I (1 principal, 1 agent). A criminal (principal) threatens to destroy a \$100 painting unless a bribe of \$90 is paid. The victim (agent) pays the \$90 to avoid the ‘sanction’ of \$100. The next day the criminal comes back with the same threat. Again the victim pays. In total, the victim has paid \$180 to save a painting only worth \$100 – in other words, the total effect of the ‘sanction’ of \$100 is multiplied by 2 because the threat to destroy the painting is repeated.

The example also illustrates the fundamental cause of the multiplication effect: when the agent complies on the first day, the stick is not ‘applied’ and hence the threat to apply it can be repeated on the second day.

The multiplication effect would not have been possible had the principal worked with a carrot instead of a stick, because he would have lost the carrot by paying it to the obeying agent on the first day and could not have come back with the same reward the next day. The reason is that when the agent complies and receives the reward of \$100, the principal loses the ability to incentivize. He cannot promise to pay the same \$100 again, since he has already transferred the \$100 to the complying agent. In other words, by using the carrot, the principal loses it – at least if the incentive mechanism is effective and the agent complies. When the agent does not comply, the carrot does not have to be paid and can be reused, but this does not lead to a multiplication effect since, when the agent does not comply, the carrot has no effect; therefore, a carrot of \$100 can never have an effect of more than \$100.

Example II (several principals, 1 agent). A criminal (principal) threatens to destroy a \$100 painting unless a bribe of \$90 is paid. The victim (agent) pays the \$90 to avoid the ‘sanction’ of \$100. The day after another criminal comes back with a similar threat. Again the victim pays. In total, the victim has paid \$180 to save a painting worth only \$100. While in the first example we had 1 agent, 1 principal, and several periods, here there is 1 agent and several principals, but the outcome is similar.

Example III (1 principal, several agents). The world is governed by a dictator who owns just 1 bullet (which could kill 1 person). With this single bullet, the dictator incentivizes 6 billion people. Assume the value of each life is 1000 and the effort required by the dictator from each individual is 999. With 1 stick of 1000 (the bullet), the incentive effect

is $999 \times 6,000,000,000$. While it would be better for all agents taken as a group that 1 agent would violate the rule so that the dictator would lose his incentivizing power, no agent has an individual incentive to do so. Although the principal can use the bullet only once, all the 6 billion agents react to the treat.

The fundamental reason why the multiplication effect takes place is a coordination problem. In example 3, there is no coordination between several agents. Examples 1 and 2 can be interpreted as a coordination problem between one agent's decisions at different moments in time (while facing the same or different principals). In this respect one could say that only sticks allow principals to organize prisoner's dilemmas among their agents. Sticks are more vulnerable to exploitation by the enforcer than carrots, and hence they should be used with more caution.

From a different perspective, since the same carrot cannot be used twice, the choice of carrots as a means of enforcement entails an implicit commitment on the part of the principal not to repeatedly apply the same sanction. Carrots are better commitment devices: by paying the carrot the principal makes it impossible to use it again. The same commitment needs to be quite explicit in the case of sticks, as it is indeed possible for the principal to repeatedly use the same stick. This possibility may prevent parties from entering contracts, or more generally, situations in which enforcement is based on sticks, since they may fear to be subject to the same stick indefinitely, in a sort of blackmailing.

We show that sharing rules can be an implicit way for the principal to commit not to repeatedly use a stick. We show that law and private contracts try to overcome the problems generated by the multiplication effect in either of two ways: interdicting sticks (and favoring carrots) or inducing cooperative behavior. We also show that when parties realize the risk of over-exploitation associated to the multiplication effect, they might decide to forgo otherwise profitable deals.

The multiplication effect has important consequences for law enforcement. Mass enforcement, in fact, is usually based on sticks; ancient and modern states, dictatorships and democracies largely rely on sticks to prevent crime. It is puzzling that, although no modern state has enough resources to prosecute, try, and punish more than a very limited number of people – that is, the threat to punish everyone is not credible⁴ – most people obey the law.⁵ Common sense

⁴ To clarify, a stick that is not credible in the aggregate may yet be credible at the individual level. On the contrary, as we will explain, a carrot must be credible in the aggregate to be credible at the individual level. In the framework of

suggests that this is because, although there are not enough police, courts, and prisons to punish everyone, no one wants to be the next to be punished.

We demonstrate that the multiplication effect has many other pervasive consequences in economics and law and provides a unified explanation for seemingly unrelated topics such as the widespread availability of legal aid, the occurrence of riots and revolutions (and the function of curfews and the right to associate), the use of divide-and-conquer strategies, the social function of comparative negligence (preventing unintended overdeterrence in tort law), the dominance of property rules in economic systems (and the multiple takings problem of liability rules), the tragedy of the anticommons, the most-favored-nation clause in settlement of litigation, and legal restrictions on the use of financial sanctions in employment relationships.

Section 2 contains our basic model and shows that only sticks can be multiplied; section 3 provides an interpretation of the formal analysis and extensions; section 4 shows that sharing rules limit the multiplication effect, and discusses other measures that prevent the multiplication effect; section 5 discusses measures that facilitate the multiplication effect; section 6 discusses some applications of our findings; and section 7 concludes.

2. Analysis

2.1. Model

We consider three risk-neutral, utility maximizing parties, a principal P and his two agents⁶ – Row and Column – who are already in a relationship.⁷ The timing of the game is as follows. At t_1 , the principal announces the rule and the sanction; at t_2 , the agents independently decide

our paper we consider that a threat to punish is as credible as a promise to reward for each individual. Indeed, we believe that there is no a priori theoretical argument to contend that one is more or less credible than the other. An empirical confutation of this claim would not undermine our point, as we say that, all other things being equal – including the credibility issue – sticks are subject to a multiplication effect.

⁵ Arguing that people obey the law for other reasons than fear to be punished or desire to be rewarded does not undermine our point. In fact, we restrict our analysis to those individuals that indeed obey the law in order to avoid a punishment or receive a reward and argue that, if sticks are employed, people obey the law even if the enforcer has not enough resources to punish everyone and, thus, the threat that everyone who violates the law will be punished is not credible in the aggregate.

⁶ We further assume that the agents can be identified ex ante on the basis of some criterion (for example, the victim vs. the injurer in an accident, or the individual who moves first vs. the one who moves second). If agents cannot be identified ex ante, they cannot perfectly anticipate who will be punished or rewarded according to the rule in force and they will only bear a statistical expectation.

⁷ The decision whether to enter the relationship is uninteresting at this point. We will discuss this issue in the next sections.

whether to comply or to violate; at t_3 the principal always applies the sanction as announced at t_1 (i.e. a carrot S^+ follows compliance or a stick S^- follows violation). For simplicity, we assume that each agent can take only two actions. Compliance yields a positive benefit B to the principal and triggers a positive cost C for each agent. In particular, B accrues only if both parties comply. Violation yields no benefit for the principal and it is costless for the agents.

2.2. Carrots

Let us assume the principal announces that enforcement will be based on carrots. If an agent complies he will be rewarded, if he violates no sanction will be applied; if both comply, the carrot will be allocated according to some share $\sigma \in [0,1]$. The normal form of the game is illustrated in figure 1.

[Figure 1]

Proposition 1. If enforcement is based on carrots, the aggregate carrot to apply to the parties must at least be equal to the sum of the parties' costs of compliance in order for both parties to comply.

Proof. It is easy to see that a party will comply if and only if his share in the carrot is at least equal to his cost of compliance, that is, if the payoff of compliance is positive. With this condition in mind, there are three possible outcomes.

1. $S^+ \geq 2C$: there obviously exists a σ such that $\sigma S^+ \geq C$ and $(1-\sigma)S^+ \geq C$;⁸ comply is the dominant strategy for both parties, comply/comply (II) is the only Nash equilibrium of the game;⁹
2. $2C > S^+ \geq C$: there exists no σ such that $\sigma S^+ \geq C$ and $(1-\sigma)S^+ \geq C$; there are two sub-cases:
 - 2.a. if $\sigma S^+ < C$ and $(1-\sigma)S^+ < C$,¹⁰ when a party violates, the other party's best response is to comply and, conversely, when a party complies the other party's best

⁸ One such sharing is $\sigma=1/2$, since we have assumed for simplicity that agents have identical costs of compliance.

⁹ If σ is set such that $\sigma S^+ \geq C$ and $(1-\sigma)S^+ < C$ or $\sigma S^+ < C$ and $(1-\sigma)S^+ \geq C$ the solution is trivially the same as in case 2.b below. It is easy to show that σ cannot be set such that both $\sigma S^+ < C$ and $(1-\sigma)S^+ < C$, since this would imply $S^+ < 2C$.

¹⁰ This occurs for example when the carrot is shared equally, as $2C > S^+$ implies $C > S^+/2$.

- response is to violate; there are two Nash equilibria: comply/violate (I) and violate/comply (III);
- 2.b. if $\sigma S^+ \geq C$ and $(1-\sigma)S^+ < C$ or $\sigma S^+ < C$ and $(1-\sigma)S^+ \geq C$, one party's dominant strategy is to comply and the other party's best response is to violate; there is only one Nash equilibrium, which is either comply/violate (I) or violate/comply (III), respectively;
3. $S^+ < C$: there exists no σ such that $\sigma S^+ \geq C$ or $(1-\sigma)S^+ \geq C$; the dominant strategy is to violate for both parties, violate/violate (IV) is the only Nash equilibrium of the game. ■

2.3. *Sticks*

Now let us assume the principal announces that enforcement will be based on sticks for violators, while no consequence will follow for compliers; if both violate, the sanction will be shared according to σ , as in figure 2.

[Figure 2]

Proposition 2 (multiplication effect). If enforcement is based on sticks, the aggregate stick to apply to the parties must be at least *equal to the cost of compliance of one party* in order for both parties to comply. If parties can cooperate, sticks yield both parties' compliance at the same condition as carrots.

Proof. Assume $\sigma \in \{0;1\}$. It is easy to show that, if $S \geq C$, one party's dominant strategy is to comply and the other party's best response is to comply. If parties can cooperate – that is, if they can agree on a common strategy and compensate each other – it is easy to see that they both will comply only if $S \geq 2C$, because if and only if this condition is satisfied is their aggregate payoff positive. ■

2.4. *N-agent, n-principal, and n-period games*

Our results can be easily extended to n -agent games: applying proposition 1, when there are n

agents, they will all comply under carrots only if $S^+ \geq nC$.¹¹ More interesting is to analyze the effect of an increase in the number of agents on the multiplication effect of sticks.

Proposition 3 (multiplication with n parties). The multiplication effect of sticks is equal to the number of agents.

Proof. Consider that there are n agents and assume they are somehow ordered so the enforcer first looks at the party that comes first in the ordering. If that party has violated the rule, the stick is applied entirely to that party and the game ends. Otherwise, the enforcer looks at the following party. It is easy to show that, in the absence of coordination and if $S \geq C$, it is optimal for each party to comply. Hence a stick of magnitude S^- has the same incentive effect as a carrot n times larger. ■

It is easy to show that this proposition also applies to n -period games with the same or different principals, a point that we will discuss in the next section.

3. Interpretation of the results and extensions

The analysis of the previous section shows that, in order to obtain the same result in terms of incentives, enforcement based on sticks requires the application of sanctions of lower magnitude than the carrots that would otherwise be necessary. This result is intriguing, as it cannot be explained by any other feature of the game but the sign of the sanction. To our knowledge, there is no contribution in the literature that links the effects of an enforcement mechanism to the sole sign of the sanction being applied in a standard rational-choice setting.

Nevertheless, the logic of this result is easily understood by considering the way in which sticks create incentives. When Row is threatened by a stick whose magnitude overcomes the cost of compliance, his optimal reaction is to comply. However, when Row complies, the stick does not need to be applied and can be recycled to incentivize Column.

The same mechanism cannot work with carrots. In fact, when a carrot of magnitude greater than the cost of compliance is promised to Row and he complies, another carrot of the same magnitude is necessary in order to incentivize Column. It is easy to see that to incentivize two agents, the principal needs a carrot which is twice the magnitude of the stick.

¹¹ An appropriate sharing in this case is $\sigma=1/n$.

3.1. *The logic of the multiplication effect*

Now let us take a closer look at the logic of this result. Sticks enjoy the advantage of a divide-and-conquer strategy. The timing of the attack is as follows: a party is threatened, the threat succeeds, the party complies, and finally, the threat is reused against another party. It is the logic of the prisoner's dilemma. As a matter of fact, if parties were able to cooperate, they would choose comply/comply under sticks at the same condition as under carrots, and the multiplication effect would disappear.

Thus, the multiplication effect is crucially based on the impossibility for the parties to coordinate their actions. First it is necessary to divide them and only then it is possible to conquer them through the use of sticks that would otherwise be too small.

3.2. *Sequential games*

Our analysis is based on a two-agent simultaneous game, but the same result holds in a one-agent two-period game, in which an enforcer sequentially applies the same enforcement mechanism to the same party. The timing of the game is as follows: at t_1 , the principal announces the rule and the sanction; at t_2 , the agent decides whether to comply or to violate; at t_3 the principal applies the sanction as announced in t_1 ; at t_4 , the same principal announces the second rule and the sanction; at t_5 , the agent decides whether to comply with this second rule or to violate it; at t_6 the principal applies the sanction as announced in t_4 . It is easy to see that if some reasons exist as to why the party fails to see beyond the current period, the results derived in the formal analysis also apply here.

Example 1 may be instructive (a victim paying \$90 to a first criminal who threatened to destroy the victim's painting worth \$100 and paying another \$90 the next day to a second criminal who threatened to destroy the same painting). The decision to pay the bribe is optimal in each individually considered period, as is the decision to confess individually optimal for each prisoner in the dilemma. However, both choices are short-sighted. If the victim had anticipated that the criminal would have come back the next day, it would have been wise not to pay in the first place and to let the criminal destroy the painting (a loss of \$100 instead of \$180). Short sight can be analogized to a coordination problem between different periods and plays the same role as a lack of coordination in traditional prisoner's dilemmas.

Figure 3 and 4 show the extended form of the sequential game. It is easy to see that, as we

have already proved for simultaneous games, a single punishment can be used to sequentially threaten both parties; moreover, in equilibrium neither party is punished. On the contrary, two rewards are necessary – one for each party – in order to provide the same incentives. Also proposition 3 can be straightforwardly applied: the multiplication effect is equal to the number of periods.

[Figures 3 and 4]

3.3. *Several principals*

Our results also straightforwardly apply in the case of one agent facing multiple principals, who all sequentially can use the same stick. It is easy to see that this situation is analytically identical to the sequential game just described and that all of our results apply. Reconsider the example of the criminal, but now assume that the next day it is not the same criminal who comes back, but another one. The victim's position is the same as in the previous section.

3.4. *Does the multiplication effect increase or decrease social welfare?*

In essence, the multiplication effect is a tool that makes sticks more powerful, and enforcement based on sticks cheaper. In this respect, there is an analogy between the multiplication effect and cheaper (or for the same price better) weapons to policemen or soldiers, which allow to obtain the same military effect at a lower price. Because enforcement becomes cheaper, the multiplication effect may allow enforcing additional rules that would be too costly to enforce in the absence of a multiplication effect. Though this saving on enforcement costs is always an X-efficiency gain, the overall effect on social welfare depends to a large extent on the social desirability of the additional rules. The multiplication effect makes it easier for a benevolent enforcer to make society better, but also easier for a non-benevolent dictator to make society worse.

3.5. *Multiplication effect versus other types of principal's opportunism not considered*

We have assumed that the principal behaves at t_3 as announced at t_1 (and that in a sequential game, the principal will also behave at t_6 as announced at t_4). We have excluded the problem of the principal's opportunism at t_3 from the analysis for two reasons. First, it affects both sticks and carrots in symmetrical ways. Under a stick system the principal's opportunism may consist in (a) falsely sanctioning a complying agent, (b) not sanctioning a shirking agent, or (c) changing the

magnitude of the sanction ex post (which may occur in particular when applying the stick is costly to the principal, as in case of imprisonment). Under a carrot system the principal's opportunism may consist in (d) not rewarding a complying agent, (e) rewarding a shirking agent, or (f) changing the magnitude of the sanction ex post.

Second, there is fundamental difference between cases in which the agent regrets to have complied at t_2 when she notices the principal's opportunism at t_3 , and the multiplication effect in a strict sense, as can be illustrated by the following two examples.

Example IV (insolvent principal, 1 agent). The principal promises at t_1 that if the agent renders a service that costs \$90 at t_2 , the principal will pay a \$100 bonus at t_3 . However, the principal is only able to pay \$10 at t_3 . Here the agent spent \$90 to obtain a bonus that in reality was worth \$10. Has this carrot of \$10 had a 'multiplication effect' so that it incentivized for \$90?

In this case the principal lies with respect to the magnitude of the carrot: he promises a reward of \$100 but is only able to pay \$10. The same can occur with sticks when, for example, the stick is costly to apply. An enforcer might lie with respect to the length of the imprisonment term to which a violating agent is subject: he may announce that the agent will spend 10 days in prison (which we assume is equivalent to \$100 for the agent), while he only has money to run the prison for 1 day (\$10). It is evident that lying about the magnitude of the sanction does not amount to a multiplication effect as described above and, moreover, such behavior has the same effects under carrots and sticks. The point we make in this article is that, even if principals are not opportunistic at t_3 , there is a difference between sticks and carrots.

Example V (1 principal, 1 agent, second effort required for bonus). The principal promises at t_1 that if the agent renders a service that costs \$90 at t_2 , the principal will pay a \$100 bonus at t_3 . However, the principal refuses to pay the \$100 bonus at t_3 and requires the agent to render a second service of \$90 in order to get the \$100. Suppose the agent does indeed render this second service. Has this carrot of \$100 had a multiplication effect so that it incentivized for \$180, similar to Example I?

It is easy to see that this case is different from the multiplication effect. First of all, the principal's behavior is equivalent to cheating with respect to the payment of the carrot. In fact, although the agent has performed in t_2 , he does not receive the carrot in t_3 . This is the only reason why the

carrot can be reused. The same could be done with sticks: even if the agent does not comply, the punishment is not applied and hence can be used again. In the case of both the carrots and the sticks, this type of behavior hinders the credibility of the principal's promises or threats in the long run. In the analysis of the previous sections, we have instead considered situations in which sanctions are applied as announced and in which the credibility issue does not arise.¹²

3.6. *Rent-seeking contests*

According to the Tullock paradox (Tullock, 1967, Tullock, 1980, Tollison, 2003), parties in a rent-seeking game may in total exert more effort than the prize at stake. Is this over-dissipation of rents in contradiction with our statement that the effect of a carrot cannot be multiplied?

In our analysis we have considered cases in which the sanctions are individually aimed at specific agents and in which the behavior required to avoid the punishment (or earn the reward) is also defined at the individual level. In the rent-seeking races Tullock considered, a prize is promised to the first agent who reaches a certain result. In such games, parties with increasing marginal returns to effort may in theory be induced to exert in total more effort than the prize at stake or the punishment to be avoided,. However, two features of Tullock's paradox will be helpful to explain why this is not the case.

First of all, rent-seeking games are symmetrical with respect to the sign of the sanction, that is, the model does not change whether parties compete to earn a prize or to avoid a punishment. Thus, contrary to our analysis, over-dissipation does not yield different conclusions for carrots and sticks and hence it cannot be used as an argument to distinguish between the two.

Second, more recent literature has shown that there may indeed be situations in which the parties spend in total more than the rent, but such incidences of over-dissipation are counterbalanced by cases in which they spend much less, so that the sum of the ex ante expected efforts by the parties is at most equal to the contested rent, which amounts to no multiplication at all (Baye, Kovenoch and de Vries, 1999, Dari-Mattiacci and Parisi, forthcoming).

4. **Solutions: stopping the multiplication effect**

In this section we analyze which arrangements can stop the multiplication effect. Preventing this effect can be a goal of agents who want to lower the enforcement level of the rules that are costly

¹² Also see footnote 4 on credibility of threats and promises.

to them, or who want to break the political power of the enforcer. Enforcers may also find it desirable to prevent competing groups (such as criminal or political organizations) from multiplying the incentive effects of sticks. Benevolent enforcers may also wish to prevent unintended multiplication effects when they work with sticks that are only meant to internalize some negative effects (so that decisions can be made at a more decentralized level, for instance by the potential injurer in an accident context), and they want to be sure that there is no overdeterrence.

4.1. *Explicit contracts between the agents and rules that facilitate cooperation among agents*

Since the fundamental cause of the multiplication effect is the lack of coordination between agents, the most straightforward way to prevent the multiplication effect is to allow and facilitate explicit contracts between the agents. For instance, the right-to-associate is a rule that allows for coordination among citizens and hence can be considered as a way to limit the power of the state.

4.2. *Sharing rules as a form of implicit cooperation*

Sharing rules are implicit ways to make the agents cooperate: in essence, they are the hypothetical contracts that rational agents would have written if they had the chance to do so. Here we examine two rules that share the sanction equally among the agents and show that they counteract the multiplication effect. The rule we consider first is analogous to the comparative negligence rule in torts: the sanction is shared only if both parties violate. The rule we consider second is analogous to collective responsibility: the sanction is shared whenever either party violates.

Proposition 5 (comparative-negligence type of sharing rules). In enforcement with sticks, if the sanction is equally shared only when all parties violate, comply/comply is not the only Nash equilibrium unless the aggregate stick is at least equal to the sum of the parties' costs of compliance.

Proof. Let us start from the 2-party game and consider a case in which the multiplication effect normally arises: $2C > S \geq C$. It is easy to verify from figure 2 that if $\sigma=1/2$ both comply/comply (II) and violate/violate (IV) are Nash equilibria. In addition, violate/violate would be preferred by the parties over the other equilibrium as it yields lower costs. On the contrary, if $S \geq 2C$, then

comply/comply is the only Nash equilibrium.

Now let us analyze an n party game, where $nC > S \geq C$ and $\sigma = 1/n$ if all parties violate. Let us also remark that if only some of the parties comply the sanction is equally shared among the violators and hence the share of each individual violator is greater than $\sigma = 1/n$. The outcome in which all parties comply is an equilibrium because the cost for each party that unilaterally decides to violate increases (or remains constant) from C to S . The outcome in which all parties violate is also a Nash equilibrium because the cost for each party that unilaterally decides to comply increases from S/n to C . Conversely, it is easy to show that if $S \geq nC$, then the outcome in which all parties comply is the only Nash equilibrium. ■

Proposition 6 (collective-responsibility type of sharing rules). In enforcement with sticks, if the sanction is equally shared whenever one party violates, comply/comply is the only Nash equilibrium if the aggregate stick is at least equal to the sum of the parties' costs of compliance and violate/violate is the only Nash equilibrium if the aggregate stick is less than the sum of the parties' costs of compliance.

Proof. Let us analyze a modified version of the 2-party game studied so far. Now the sanction is always shared among the parties as in figure 5. In the case in which the multiplication effect normally arises, $2C > S \geq C$, it is easy to verify from figure 5 that if $\sigma = 1/2$ only violate/violate (IV) is a Nash equilibrium. On the contrary, if $S \geq 2C$, then comply/comply is the only Nash equilibrium.

In an n party game, where $nC > S \geq C$ and $\sigma = 1/n$, the outcome in which all parties violate is the only equilibrium because the cost for each party who decides to comply increases from S/n to C . Conversely, it is easy to show that if $S \geq nC$, then the outcome in which all parties comply is the only Nash equilibrium. ■

Proposition 5 shows that sharing the sanction among violating parties opens a new strategic possibility for non-cooperative parties, in the situation in which everyone violates is also an equilibrium of the game and the one in which the cost for each party is minimized. Proposition 6 shows that sharing whenever a party violates completely overcomes the multiplication effects by inducing an implicit cooperative behavior. In this case, violate/violate is the unique equilibrium of the game. For these reasons sharing rules might hinder the reiterative incentive effects of

sticks. In fact, the effects of sharing may be compared to the effects of cooperative behavior among agents.

4.3. *Complete contracts between principal(s) and agent(s)?*

Suppose that the principal and the agent are in a contractual relationship, so that the principal's authority to enforce the rule is based on a prior agreement with the agent. Will the multiplication effect disappear when such a participation constraint is introduced? To put it differently, will rational parties to a contract ever allow enforcement that is based on the multiplication effect?

Rational parties only agree on efficient terms, and therefore the answer depends on whether the multiplication effect increases the parties' overall welfare. As explained in section 3.4, the multiplication effect is welfare enhancing when the stick is used to enforce a rule that is welfare enhancing. Therefore, complete contracts will stop the bad uses of the multiplication effect, and allow the good ones. However, this implies an assumption that parties are able to write complete contracts. If contracts are incomplete, some wealth decreasing multiplication effects may still occur.

4.4. *Forbidding sticks*

Another solution consists in forbidding sticks. This may be desirable for incomplete contracts (like employment contracts), when it is not possible to contractually rule out inefficient uses of the multiplication effect. It may also be desirable to forbid the use of sticks among individual parties outside contractual relationships. Human rights and property rights can be interpreted as rules aimed at forbidding the use of non-contractual sticks among individuals.

4.5. *Allowing sticks but forbidding multiplication*

Instead of forbidding sticks, would it not be simpler to forbid multiplication, if multiplication is the real problem? A difficulty with forbidding multiplication is that multiplication can be desirable (if it allows to save on enforcement costs, with respect to socially desirable rules, or with respect to socially undesirable rules that would otherwise be enforced at higher costs). To know whether the use of the multiplication effect is socially desirable, requires judges and regulators to acquire a certain amount of information.

A second difficulty is that the very problem does not lie in the fact that the sanction is reiterated, but in the fact that the total effort costs are higher than the magnitude of the sanction.

Even if the stick is used several times, the total effort costs can still be lower than the stick (to illustrate, suppose the agent is obliged to spend \$2 by 49 different rules, in all of which he is threatened by the same stick of \$100; in total, the agent will spend \$98 to avoid a sanction of \$100). Knowing whether multiplication resulted in excessive effort costs, requires information on the total effort costs that were required from the agent in all the commands that were enforced with the same stick. In sum, the informational requirements for forbidding socially undesirable and excessive forms of multiplication will generally be too high.

5. Making the multiplication effect stronger

In this section we analyze what can be done to make the multiplication effect stronger (or make sure it occurs in the first place). Reinforcing the multiplication effect can be a goal of principals who want to lower their enforcement costs, or increase their ability-to-enforce (or their political power).

5.1. *Forbid cooperation among agents*

Since coordination problems between agents lie at the heart of the multiplication effect, the most obvious way to reinforce the multiplication effect is to forbid cooperation among agents. An example is a curfew, which makes it harder for citizens to coordinate their actions, and easier for police forces to keep riots and revolutions under control. Another illustration is the fact that criminal gangs are generally exempted from protection on the basis of the right-to-associate.

5.2. *Reduce or give false information on future commands*

The fundamental reason why the agent does not coordinate his actions better in sequential games is lack of information in the first period. Hence, every measure that increases this information problem may increase the likelihood of multiplication.

5.3. *Non-sharing rules*

Rules that do not share the sanction when both agents violate the rule increase the likelihood of multiplication, which takes place when the *same* threat is applied repeatedly and *entirely* to different parties. In particular, our proof of proposition 2, where $\sigma=1$ or $\sigma=0$, is based on a situation where if both Row and Column violate the rule, only one of them entirely pays the

sanction. This technique makes compliance a dominant strategy for at least one party, and as a result curbs the strategy set of the other party. Put differently, the divide-and-conquer strategy functions by fully targeting one party, defeating him, and then moving to the next party.

6. Applications

In this section, we show that the multiplication effect is the underlying logic of several seemingly unrelated problems in economics and law.

6.1. *Legal aid*

Legal aid is a public subsidy of the legal expenses incurred by low-income parties. Although it exists in many jurisdictions, it is often criticized in the economic literature. Legal aid is not only believed to distort incentives, but it is also a benefit in kind (Posner, 1977), which economists generally consider as an inferior method of redistributing income, compared to the income-tax system (Kaplow and Shavell, 1994, 2000).

The multiplication effect, however, may offer a new justification for this redistribution in kind. Legal aid is a special form of redistribution indeed: it is a subsidy that in principle never has to be paid. The mere availability of the subsidy makes the threat of using the legal system credible, which generally will be sufficient to induce the other party not to violate the law. Hence, a single subsidy for one court case may help thousands of poor parties, all of which can threaten to go to court, but almost never have to do so. This multiplication effect makes this form of redistribution-in-kind more effective than a direct redistribution of income through the income tax or social security system. To put differently, redistribution in kind may allow solving a problem (that has its origins in the unequal distribution of income in society) with less redistribution than the direct redistribution of income through the tax system.

6.2. *Riots, curfews, and the right to associate*

The multiplication effect can offer a more fundamental explanation for how riots break out. Haddock and Polsby (1994) emphasize that mobs tend to be under control until a certain signal (such as someone breaking a window) convinces everyone that a riot is starting. The function of the signal is one of coordination. As Haddock and Polsby put it, “with the police watching, who would be brave enough to cast the first stone?” If only a few people revolt, they face a high

probability to be sanctioned, as the police can focus their efforts on them. But once a riot has started, virtual immunity is guaranteed to almost all participants, and police forces have enormous difficulties to get it back under control.

Police enforcement against riots (and other forms of revolutionary behavior) is based on sticks. Stick systems can save costs by using the multiplication effect. Thus, a small police force may succeed in controlling large populations by relying on the fact that the threat of punishing, although unrealistic for the population as a whole, is credible for its members if individually considered. However, *dividing* is a necessary condition for *conquering* through multiplication of sticks. As we have shown, coordination among the agents can annihilate the multiplicative effect of sticks. Curfews may help to prevent riots by increasing the agents' coordination costs.

6.3. *Military applications: Caesar's 'divide et impera' strategy*

That the power of sticks can be multiplied is well understood by military strategists. Julius Caesar conquered many tribes in North-West Europe with an army that was much smaller than the total of all the other armies of tribes when added together. Historians believe in the fact that Caesar succeeded in dominating a large population with a relatively small army was not only due to the technological superiority of his army (better weapons) but also to his strategy of internally dividing the tribes, and to the speed at which he often intervened, attacking tribes before they could organize themselves (Grant, 1972). Many tribes surrendered without a serious fight, because each individual tribe realized their army was weaker than Caesar's. By surrendering, they left Caesar's stick (his army) intact. Strategies similar to that of Caesar are often referred to as *divide et impera* (divide and conquer). The multiplication effect derives from a lack of cooperation between the parties in a prisoner's dilemma type of game, which cannot possibly be reproduced in the case of carrots. The principal can induce such lack of cooperation or else simply exploit it (*divide*) in order to strengthen the incentive effects of a stick (*impera*). Without *dividing*, *conquering* by means of sticks is the same as *conquering* by means of carrots.

6.4. *Comparative negligence as a solution to unintended overdeterrence in tort law*

Tort law is a stick system: it determines which party bears the accident loss. As all sticks, the threat to bear a specific loss can in some cases have a multiplication effect. In that case, tort law may lead to unintended overdeterrence, as can be illustrated by the following example.

Example VI (joint overprecaution): an accident with a harm of \$100 can only be prevented if both the injurer and the victim take precaution (*joint care*). The precaution costs are \$90 and \$30 respectively, which means that preventing the accident is inefficient. Suppose that courts make an error in defining due care levels, and that they erroneously believe that the parties should take precaution (*informational shortcoming*). If the rule in force is contributory negligence (according to which the victim has to bear all costs when both parties are found negligent), then the victim decides to take precaution, as \$30 is lower than \$100. Given the victim's precaution, the injurer also takes precaution, as \$90 is lower than \$100. The result is that an accident is inefficiently prevented.

The fundamental cause of the overdeterrence in this example is the fact that the same stick of \$100 is used twice. Firstly, it incentivizes the victim. Secondly, the same threat to pay the accident loss incentivizes the injurer. Parties to an accident do not generally have the possibility to cooperate. Liability implements a *divide et impera* strategy and thus is vulnerable to the risk of excessive enforcement due to the multiplication effect. We noticed in the previous sections that cooperation is a way to overcome this problem. It is easy to see that if parties could cooperate they would agree not to take precaution in case and split the accident loss in some way that makes both of them better off. While explicit cooperation is generally not possible in accident contexts, cooperative behavior can nevertheless be induced by sharing rules. A sharing rule that satisfies these conditions is a modern comparative negligence rule, under which the loss is not shared equally but in accordance to the prevention costs (75/25).¹³ Comparative negligence implicitly enhances cooperative behavior between the parties to an accident and hence prevents the multiplication effect.

This point may help explain why comparative negligence is the most common liability rule across modern legal systems – a puzzle that has not been fully resolved in the literature. The generally accepted efficiency-equivalence theorem (Landes and Posner, 1980) states that all negligence rules provide, in principle, equivalent incentives to take optimal care. Comparative negligence, however, is believed to generate higher administrative costs than its all-or-nothing alternatives (e.g. Low and Smith, 1995).¹⁴ It should be noted that our explanation is based on two

¹³ The game has now two equilibria, one in which both take precaution and one in which nobody takes precaution. Although it is not possible to say which equilibrium will dominate, the latter clearly yields a lower cost for both parties and this makes it more plausible that it will be the outcome.

¹⁴ In a recent review article Bar-Gill and Ben-Shahar (2003) criticize previous efficiency arguments pro comparative

crucial assumptions: joint care situations (in alternative care situations, where care by one party is sufficient to stop the accident, to the threat of having to bear the loss disappears for the second party once the first took care) and court errors in determining due care levels. Therefore, this overdeterrence preventing explanation may only be a part of the explanation of comparative negligence, but it illustrates the explanatory potential of the multiplication effect of sticks.

6.5. *Liability rules, property rules, and the multiple-takings problem revisited*

The multiplication effect may offer a fundamental explanation for why markets are based on property rules instead of on liability rules, by offering a fundamental explanation for the ‘multiple-takings problem’.

The distinction between property rules and liability rules goes back to Calabresi and Melamed (1972). Under a property rule protection, a transfer of a good requires the consent of the owner. Under a liability rule, a third party may ‘take’ a good without the consent of the owner, but the latter is entitled to receive full compensation, as determined by the court. Markets are based on property rules. Calabresi and Melamed (1972) explained this by noting that when transaction costs are low (so that parties can bargain) property rules are superior because they induce parties to bargain and reach efficient outcomes. Under liability rules, courts can make valuation errors since they have less information on the parties’ valuations than the parties themselves. For instance, suppose that the current owner A values his widget at \$100, while B’s valuation is \$95. If courts undervalue the widget at \$80, then B will inefficiently take A’s property under a liability rule.

However, Polinsky (1979, p. 1-4), Ayres and Talley (1995, p. 1037-1038), and Kaplow and Shavell (1996, p. 718) undermined this transaction cost explanation of property rules by arguing that, when transaction costs are low, parties bargain under a liability rule as well as under a property rule. A can indeed bargain with B, paying him to refrain. The only difference with bargaining under a property rule is that the threat points are different.

After having refuted the transaction costs explanation, Kaplow and Shavell (1996, pp. 765-766) look for alternative explanations for the existence of property rules, and found an

negligence, that were either based on evidentiary uncertainty or on different individual precaution costs in the face of uniform due care levels. Instead, our point is that comparative negligence has an advantage when levels of due care are inefficiently high, a point that has not been made in the literature and that does not fall under the above two groups of arguments. In Dari-Mattiacci and De Geest (2005) we develop a different argument for comparative negligence: sharing rules have a filtering effect because they prevent the most harmful violations and let the least harmful ones

explanation in the *multiple-takings* problem.¹⁵ This problem can occur under a liability rule when courts erroneously undervalue the good. A may refuse to pay B for not taking his widget – as we have seen it would be efficient to do – because he fears that he in the future will also have to pay a third party C in exchange of the same promise. To illustrate, reconsider the just mentioned example, in which courts undervalue the widget at \$80, while A's valuation is \$100. Since B's valuation is \$95, B's gain from taking the widget and paying compensation is \$15; therefore, A must offer B at least the same, which is convenient for A, as he would otherwise lose \$20. Imagine, however, that there is the possibility that after A has concluded the deal with B, a party C – with the same valuation as B – comes and threatens A to take the widget. Once more, it would be convenient for A to pay C at least \$15 not to take the widget. The result of the two bargains is that A ends up paying at least \$30 in total to avoid suffering a loss of only \$20. If he anticipates this outcome, he will not be willing to deal with B in the first place and, thus, the widget will end up in the hands of the lowest-value user. A similar problem is the *reciprocal-takings problem* – under which B takes from A and, successively, A re-appropriates the widget from B.

According to Kaplow and Shavell (1996), the multiple takings problem can explain the general use of property rules in low transaction cost situations. The same logic was earlier used by Demsetz (1967, p. 357) in the context of explaining why private property triggers lower transaction costs than common property (in common property one has to negotiate with all owners to stop an harmful externality). However, they do not offer a more fundamental explanation for why property rules are not equally affected by this problem.

The multipliability of sticks can offer a simple, fundamental explanation. A property rule always creates a carrot system, while a liability rule can create a stick system if compensation is set too low. Sticks are affected by the multiplication problem, carrots aren't. If the rule is a property rule, the owner does not face a stick but a carrot, in that the potential taker offers a sum in exchange for the widget. If the rule is a liability rule, and courts undercompensate, the

occur.

¹⁵ Kaplow and Shavell (1996) explain the use of liability rules in accident contexts by the fact that they deal with harmful externalities, which are less vulnerable to multiple takings (and correlated-value problems) than tangible things. Ayres and Balkin (1996) and Ayres and Goldbart (2001) argue that the multiple-takings problem cannot explain the use of property rules, since in theory it could be solved if courts would impose higher damages for successive takings (mimicking a more efficient auction). However, the absence of real-life examples suggests that the informational requirements for such a refined compensation system are enormous. Therefore, the point implicitly comes down to stating that in a world in which courts operate at no costs liability rules are not undermined by the

potential taker B may extract a payment from the owner A by threatening him with a stick: causing a loss by taking the widget at a too low price. After the owner has paid the first potential taker a sum not to take the widget, the second potential taker can threaten the owner to use the same stick as the first potential taker: he threatens to take the widget unless the owner pays a sum. It is easy to see that a multiplication effect is taking place, since the threat to use the same stick is reiterated towards the same agent (the owner) by two different principals (the two potential takers). The multiple takings problem is, thus, only a manifestation of the multipliability of sticks, and obviously yields the same consequences. The owner may end up paying either more than the harm he seeks to avoid or, if he realizes the risk of being exploited, he may not bargain in the first place, which is inefficient, since the widget then ends up in the hands of a taker, who has a lower valuation than the owner.

6.6. *Anticommons revisited*

When several parties jointly hold exclusion rights over a single resource, each party has a veto power on its use. Situations of this sort have been described as anticommons because, mirroring commons (Hardin, 1968) since they lead to an underutilization of resources (Ellet, 1839, Michelman, 1982, Heller, 1998, Shulz, Parisi and Depoorter, 2002). As we will explain, the anticommons problem is also a manifestation of the more fundamental multiplication effect that we analyze in this paper.

Consider the following example. A developer is trying to buy three neighboring pieces of valuable land belonging to different (noncooperative) owners. It is of no use for him to buy only one or two of them. Imagine that the market value for each fragment is \$30 and the value for the developer is \$100. Each of the owners holds in fact a veto right on the developer project and can threaten to use it against a bribe of \$10 (the whole developer rent). Considering each owner separately, it is rational for the developer to pay the bribe. However, in the aggregate, he will end up paying \$120 for a project he values at \$100. Microeconomic theory predicts that the larger the number of parties, the higher the price and the lower the quantity at which the anticommons will be sold in equilibrium (Buchanan and Yoon, 2000, p. 10)

The reason why anticommons and veto power lead to underutilization is that each veto right holder can threaten the potential buyer with the same stick (the blockage of the buyer's project).

multiple takings problem.

As we have explained, if there is no coordination, the stick can be repeatedly used and it will lead to over-extraction of the buyer's rent. If the buyer realizes the risk, he will not conclude the deal in the first place. It is also interesting to observe that, as in our model, the logic of the problem does not change when parties sequentially act.

As in general for reiterable threats, a straightforward solution is the bundling of the exclusion rights, the constitution of a monopoly or any other means to induce the veto right holders to cooperate. If the veto right holder behaved as a monopolist, the resulting social loss would in fact be lower than in an anticommons setting. In the example, the monopolist would try to extract the rent of \$10 from the buyer, but would not go so far as to aim at extracting \$30, as this results from the uncooperative behavior of the individual owners. Put differently, the buyer's rent represents a common good for the individual owners. Thus, in the commons logic, they will tend to overexploit it, as they earn full benefits from it but only pay a fraction of the marginal costs (in terms of decreased quantity). A monopolist instead bears the full marginal cost of rent-seeking and, thus, will not overexploit it.

6.7. *Multi-party litigation and settlement*

Our analysis also applies to settlement of litigation among one defendant and several plaintiffs. Often a defendant might have an interest in avoiding judgment on a case for a series of different reasons, which could be frustrated if one of the several plaintiffs refuses to settle. In large-scale litigation or precedent-making cases, for example, firms might not want to see their liability ascertained before the court, as this might be used against them by subsequent plaintiffs.

Each plaintiff holds in this case a veto power, since each of them can frustrate the defendant's interests by going on trial. This power can be analogized to a stick: the plaintiff threatens to punish the defendants if the latter does not agree to his settlement demands. If plaintiffs behave non-cooperatively, all of them will try to extract the total defendant's rent in a similar way as the several right holders in anticommons property try to extract the buyer's rent; the plaintiffs' demands are likely to be too high in the aggregate and the defendant may respond by refusing to settle. It has been suggested that class actions (Silver, 2000) and the most-favored-nation (MFN) clause may in fact facilitate settlement (Spier, 2003a and 2003b, and Daughety and Reinganum, 2004). The former solution is a way to induce explicit cooperation among plaintiffs. The latter induces a form of implicit cooperation by binding the range of possible offers the

defendant can make in settlement negotiations with successive plaintiffs, and hence induces an equal treatment among plaintiffs and curbs their power to extract individually higher offers.

Class actions clearly induce the several plaintiffs to behave as one and thus, solve the coordination problem in a self-evident way. MFN clauses operate in a more subtle manner. Under a MFN clause, if the defendant settles at more favorable terms with a later settling plaintiff, he will also have to pay the same to earlier settlers. The individual defendants still make their choices independently of each other. However, now, if one of the plaintiffs increases his demand, he also raises the settlements payments for all the other plaintiffs.

Without MFN each plaintiff bears the full benefit of his increases demands and only a fraction of the marginal cost due to a lower probability of settling, which is shared with all the others. With a MFN clause an increased demand has a multiplicative effect on the probability of settling and, hence, the MFN clause counterbalances the anticommons problem among several plaintiffs.¹⁶ In this sense, MFN clauses can be seen as a form of induced cooperation similar to sharing rules, and thus able to counteract the problems caused by the multiplication of sticks.

6.8. *Restrictions on negative sanctions in employment contracts*

The multiplication effect may help to explain the restrictions on negative sanctions (damages, ‘fines’, ‘penalties’) in employment contracts. These restrictions and the widespread use of positive sanction systems (like ‘bonuses’, or ‘efficiency wages’) in employment contracts stands in contrast with most commercial and consumer contracts (such as sales contracts or construction contracts) in which promisors are generally incentivized by negative sanctions, such as expectation damages (De Geest, Siegers and Vandenberghe, 2001).

Employment contracts are highly incomplete contracts. Breach is often nonverifiable, and this may also hold for breach that consists of exploiting the other party by repeatedly using the same threat. This multiplication effect is one of the reasons why stick systems are more vulnerable to opportunism. Hence, it may be dangerous to give a private party the discretionary power to use a stick when its use cannot be monitored by a court. Carrot systems are intrinsically less vulnerable to opportunism, and this may explain why they are more often used in relational contracts.

¹⁶ An analogous point is made by Spier (2003b) in section 5.2.

7. Conclusions

While punishments and rewards are symmetrical ways to induce compliance with a *single* command, they differ fundamentally when it comes to *multiple* commands. The threat to punish (a stick) is more powerful than the promise to reward (a carrot), because when parties comply, the former is not carried on and thus can be reiterated all over again, while the rewards will have to be paid and thus they are consumed with use.

We show that sticks are multipliable if agents behave non-cooperatively. The multiplication effect may be used as a powerful way to reduce government expenditures on law enforcement through the exploitation of pockets of non-cooperative behavior in the population, a strategy often denoted as *divide et impera*. However, the multiplication effect may also yield to inefficient exploitation in a relationship without an exit option, and this mechanism is actually the core of enforcement in dictatorships and criminal activities, such as blackmailing and extortion. If there is an exit option, as in contracts and settlements negotiations, parties may react to the multiplication effect by forgoing agreements that they would otherwise conclude. In law, the multiplication effect is generally tackled by prohibiting the use of sticks, by making sure the stick can be employed only once, or by inducing cooperation.

The lack of cooperation among the several parties or among the several periods in which the same party is subject to the sanction is a necessary condition for the multiplication effect to arise. In reality, a lack of cooperation is more likely to arise as a consequence of high transaction costs among multiple parties. In this case, the enforcer is likely to succeed in exploiting its agents. On the contrary, when our framework is applied to the repeated enforcement against a single party in successive periods, the likely outcome is that the party will be able to coordinate his present action with the future prospects of multiplication, refuse to comply in the first place, and hence forgo profitable contracts for the fear of exploitation.

The findings of this paper suggest a rethinking of several issues in economics and law. We have provided examples of the multiplication effect in tort liability, property, anticommons, and litigation. We suspect that the multiplication effect may help to explain several other problems that arise in private contracting, principal-agent theory and public enforcement of law.

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Figures

		Column	
		comply	violate
Row	comply	II $(1-\sigma)S^+ - C$ $\sigma S^+ - C$	I 0 $S^+ - C$
	violate	III $S^+ - C$ 0	IV 0 0

Figure 1: Enforcement with carrots

		Column	
		comply	violate
Row	comply	II $-C$ $-C$	I $-S^-$ $-C$
	violate	III $-C$ $-S^-$	IV $-(1-\sigma)S^-$ $-\sigma S^-$

Figure 2: Enforcement with sticks

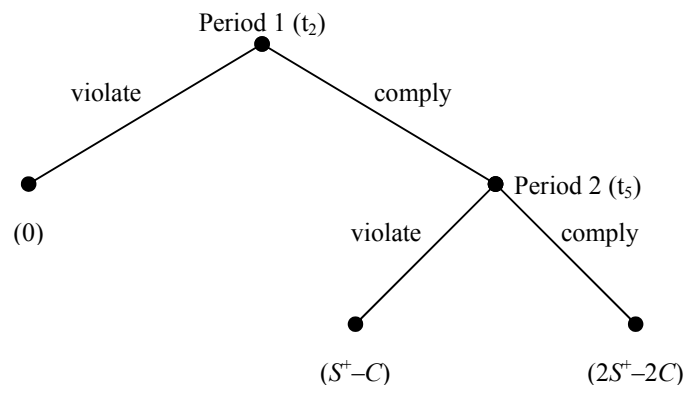


Figure 3. Enforcement with carrots in sequential games

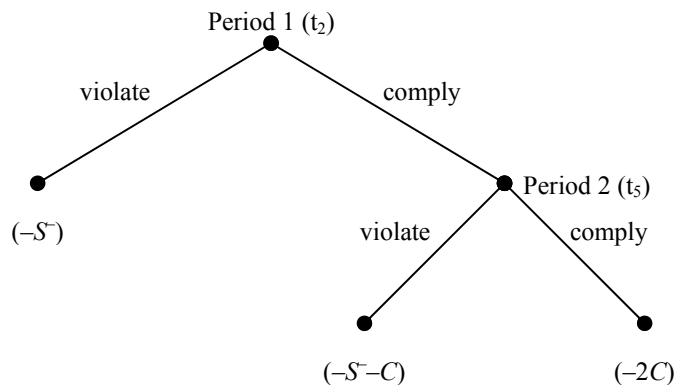


Figure 4. Enforcement with sticks in sequential games

		Column	
		comply	violate
Row	comply	II $-C$ $-C$	I $-(1-\sigma)S^-$ $-\sigma C - S^-$
	violate	III $-C - (1-\sigma)S^-$ $-\sigma S^-$	IV $-(1-\sigma)S^-$ $-\sigma S^-$

Figure 5: Enforcement with sticks under collective responsibility