Guns, Violence, and the Efficiency of Illegal Markets

John J. Donohue III; Steven D. Levitt

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By John J. Donohue III and Steven D. Levitt[*]

In economics, the standard mechanism for allocating scarce resources is the market. A smoothly functioning market, however, is built upon legally enforceable contracts and property rights. In the absence of law, it is likely that violence (or the threat thereof), rather than prices, is the means by which resources will be allocated. Interactions among animals provide clear evidence for this claim. Dominance hierarchies based on fighting ability, also sometimes known as pecking orders, have been documented across a wide variety of species (e.g., primates, chickens and other birds, reptiles, lobsters) and a broad range of resources including food, nesting sites, and access to mates (Warder C. Allee, 1938; John Alcock, 1993). Evidence suggests that violence also plays a critical role in human interactions when property rights are not legally enforceable (e.g., drug dealing and extortion) (see e.g., Peter Reuter, 1983; Geoffrey Canada, 1995).

In this paper, we analyze the determinants of the efficiency with which illegal markets allocate scarce resources. We develop a stylized model in which players compete for a fixed prize, with the winner determined by fighting ability. Efficiency in this context is determined by the amount of resources spent on fighting. Two factors affecting efficiency emerge from the model: *lethality* and *predictability*. Perhaps surprisingly, the use of more lethal mechanisms for resolving disputes does not have a clear impact on the social costs of violence. The intuition underlying this result is that, as the costs of losing a fight rise, the

willingness to fight falls. We show that holding other factors constant, the resources spent on fighting are lowest when the cost of losing is either very low or very high (e.g., nuclear deterrence), but over a wide range of lethality levels, the overall social costs of fighting are fairly stable.

In contrast, the costs of violence are critically linked to the predictability of dispute outcomes (i.e. the certainty with which potential combatants know who will be victorious *ex ante*). When the outcome of a conflict is highly correlated with observable characteristics such as strength or size, there is little need to actually fight. Thus unpredictability, all else equal, increases the expected payoff to fighting for the lower-ranked member, leading to more conflicts.

I. The Formal Model

In this section we formalize the intuition of the preceding discussion using a simple model that omits a number of potentially important considerations (e.g., private information and dynamic reputation effects). Nonetheless, the model provides a reasonable starting point for thinking formally about the issues at hand.

The structure of the model, which shares many common characteristics with the tournaments literature (Edward Lazear and Sherwin Rosen, 1981), is as follows. There are two players.[1] Each player i takes exactly one action, a_i, a decision about whether or not to fight; that is, $a_i \in \{$ fight, no fight $\}$. The players are competing for a single prize which provides a payoff W to the winner. In order to

[1] Given the functional forms we have adopted, the model readily expands to accommodate any finite number of players, although closed-form solutions become difficult to obtain. Space constraints preclude a detailed derivation of the N-player game, but we present simulation results from such models later in the paper. The model is equally applicable to individuals or groups of individuals, such as competing gangs.
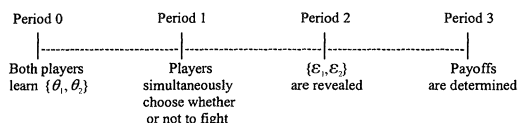
Period 0	Period 1	Period 2	Period 3
|-----------------------|	-------------------------|	-----------------------|	----------------|
Both players learn $\{\theta_1, \theta_2\}$	Players simultaneously choose whether or not to fight	$\{\varepsilon_1, \varepsilon_2\}$ are revealed	Payoffs are determined

FIGURE 1. THE TIMING OF THE GAME

be eligible to win the prize W, a player must fight. If a player fights and loses, he receives a payoff $-C < 0$. Players who elect not to fight receive a default payoff normalized to zero.

Each player is characterized by a fighting ability F_i, where

$$(1) \qquad F_i = \theta_i + \varepsilon_i.$$

What we will hereafter refer to as the observable component of fighting ability, $\{\theta_1, \theta_2\}$, is common knowledge to both players; $\{\varepsilon_1, \varepsilon_2\}$, on the other hand, is unobservable, even to the player himself (i.e., player i does not know ε_i). This unobservable component can be thought of as randomness in fight outcomes. The θ's are independently and identically distributed normal with mean zero and variance equal to $0.5\sigma_\theta^2$. The ε's are assumed to be independently and identically distributed with a type-1 extreme-value distribution,[2] characterized by

$$(2) \quad \Pr[\varepsilon_i \le \varepsilon] = \exp[-\exp(-\varepsilon/\sigma_\varepsilon)].$$

This distribution proves to be extremely tractable, as will become apparent. Visually, the type-1 extreme-value function resembles a normal distribution, but with a thick right tail. The σ_ε^2 term influences the dispersion of the distribution.

The timing of the game is as shown in Figure 1. In period 0, the observable components of fighting ability (the θ's) become common knowledge. Based on this symmetric (but incomplete) information on fighting abilities, the players simultaneously choose whether or not to fight. After each player decides whether or not

to enter the fight, the unobservable components of fighting ability $\{\varepsilon_1, \varepsilon_2\}$ are revealed, and the winner is determined. The winner is the player with the highest value of F_i among the set of players who elected to fight in period 1. If only one player chooses to fight, he automatically wins the prize W. If neither player opts to fight, no prize is awarded.

It is immediately evident that equilibrium must involve at least one player choosing to fight. For those equilibria involving one player choosing to fight and the other electing not to fight, no fight occurs and there are no resources expended on fighting.[3] Only when both players elect to fight will a fight take place.

Let P_i equal the probability that player i wins the prize W conditional on both players choosing to fight:

$$(3) \qquad P_i = \Pr(W_i \mid \theta_1, \theta_2, \sigma_\varepsilon)$$

$$= \Pr(\theta_i + \varepsilon_i > \theta_j + \varepsilon_j).$$

In general, there is no simple numerical solution to the relationship in equation (3). It has been shown, however, that if two independent random variables each have the same type-1 extreme-value distribution, then their difference has a logistic distribution (Norman Johnson and Samuel Kotz, 1970; Domencich and McFadden, 1975). It is this result that motivates our earlier distributional assumptions. Consequently, P_i can be expressed as

$$(4) \qquad P_i = \frac{\exp\left(\dfrac{\theta_i}{\sigma_\varepsilon}\right)}{\exp\left(\dfrac{\theta_1}{\sigma_\varepsilon}\right) + \exp\left(\dfrac{\theta_2}{\sigma_\varepsilon}\right)}.$$

Given P_i, player i chooses to fight if and only if the expected payoff to fighting is

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[2] Thomas Domencich and Daniel McFadden (1975) refer to this distribution as "Wiebull (extreme value, Gnedenko)." We thank James Heckman for suggesting this functional form.

[3] Which of the two players chooses to fight in such equilibria will depend not only on the parameters of the model, but also on player beliefs. Equilibria involving both players fighting (our primary focus) will not depend on player beliefs.

greater than the default payoff of not fighting, or mathematically,

$$(5) \qquad WP_i - C(1 - P_i) \geq 0.$$

In order for a fight to occur, both players must satisfy equation (5). Noting that $P_1 + P_2 = 1$, the conditions for a fight can be written as

$$(6) \quad \frac{P_1}{P_2} \geq \frac{C}{W} \quad \text{and} \quad \frac{P_2}{P_1} \geq \frac{C}{W}.$$

Substituting equation (4) into equation (6), taking logs, and rearranging yields

$$(7) \qquad \theta_1 - \theta_2 \geq \ln\left(\frac{C}{W}\right)\sigma_\varepsilon$$

$$\theta_1 - \theta_2 \leq -\ln\left(\frac{C}{W}\right)\sigma_\varepsilon.$$

The first expression is the cutoff for player 1's willingness to fight; the second expression is the threshold for player 2. The larger the cost associated with fighting and losing relative to the prize, the less willing players are to fight. If $C > W$, then those two conditions can never be simultaneously satisfied, and there will never be a fight. Intuitively, $C > W$ means that the combined expected payoff given that a fight occurs is negative, implying that at least one player must have an expected payoff that is negative. As long as $C < W$, the log term is negative, allowing for the two conditions to be simultaneously satisfied. The greater is the uncertainty in the determination of the fight outcome (i.e., the greater is σ_ε), the higher the chances that the player with the lower observable fighting ability will be victorious. Since it is always the weaker player who represents the binding constraint on a fight occurring, less predictability of fight outcomes will lead to more fights.

The expression in equation (7) is conditional on the particular values of θ that are observed. In order to make general statements about the probability of fights, one must integrate over the joint distribution of θ_1 and θ_2. Because of the normality assumption for θ, the difference between the two θ's is itself normally distributed. Figure 2 captures pictorially the likelihood that a fight occurs. The
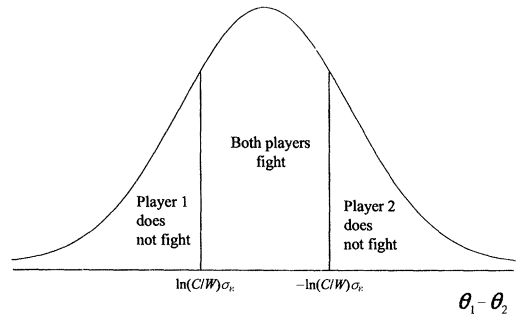

FIGURE 2. THE CONDITIONS UNDER WHICH A FIGHT OCCURS

probability density function of $\theta_1 - \theta_2$ is pictured in the figure. The symmetric vertical lines to the left and right of center represent the cutoff points below which player 1 and player 2 respectively choose not to fight. The middle area between the two lines represents the probability that a fight will occur. Increasing C, lowering W, or reducing σ_ε will shift the vertical lines inward, reducing the number of fights. Increasing the variance of $\theta_1 - \theta_2$ reduces the mass in the middle area, also reducing the number of fights.

Noting that the variance of $\theta_1 - \theta_2$ is σ_θ^2, the unconditional probability that a fight occurs can be expressed as

$$(8) \qquad \Pr(\text{Fight occurs})$$

$$= 1 - 2\Phi\left[\frac{\sigma_\varepsilon}{\sigma_\theta}\ln\left(\frac{C}{W}\right)\right]$$

where Φ represents the cumulative distribution function of the standard normal distribution. The term after the minus sign is the weight outside the vertical lines in Figure 2. Equation (8) provides an extremely convenient and intuitive characterization of the likelihood of a fight: (i) the relative importance of unobserved factors in determining fight outcomes (the ratio of the σ's), which we will call *predictability*, and (ii) the log ratio of the costs of losing relative to the prize for winning, which we term the *lethality* of the fighting technology.

It is not simply the number of fights that matters, however, but rather the amount of resources expended in fighting that is of primary importance. Thus, we consider a variable

V (for violence) which is the expected value of the costs associated with fighting, obtained by multiplying equation (8) by C:

$$(9) \quad V = C\left(1 - 2\Phi\left[\frac{\sigma_\varepsilon}{\sigma_\theta}\ln\left(\frac{C}{W}\right)\right]\right).$$

Understanding the relationship between the costs of violence V and the parameters it depends upon is best accomplished visually. Figure 3 presents a graph of V as a function of the lethality and predictability of fight outcomes. Throughout the graph, W is held fixed at 100. Moving from left to right, C is allowed to vary from 0 to 100. The three lines traced out on the graph represent three different values of predictability. The curve labeled "most predictable" has a ratio of $\sigma_\varepsilon/\sigma_\theta = 0.1$. The "somewhat predictable" curve has a ratio of 0.5, and the "least predictable" curve has a ratio equal to 1. Moving along a given curve (i.e. holding predictability constant), rising lethality initially increases the costs of violence but then lowers it. At the two extremes, there are no costs of violence. When $C = 0$, fighting carries no costs; when $C = W$, fights never occur. The downward-sloping part of the curve underlies the logic of nuclear deterrence.

Comparison across curves demonstrates that predictability is strongly related to the costs of violence. For middle ranges of lethality, the costs of violence are roughly 25 percent of the prize being fought over in the least predictable case, but only 3 percent in the most predictable case. When players have better information *ex ante* about who will emerge victorious, the number of fights is lower.[4]

The same patterns observed in Figure 3 emerge more strongly as the number of players in the game increases. Space constraints preclude a full accounting of the N-player game. It is worth reporting simulation results for a five-player version of the game with $W = 100$, which we have described more fully in Donohue and Levitt (1997). While the curves traced in that game rose and fell with lethality as in Figure 3, the most striking feature of the simulations was that over a wide range of values for lethality ($20 < C < 80$), there
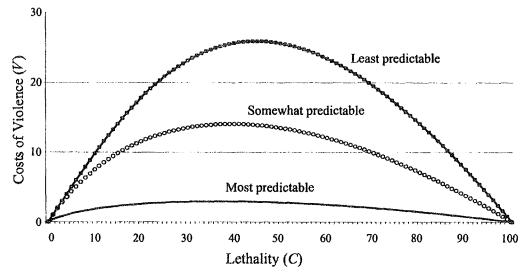

FIGURE 3. THE IMPACT OF LETHALITY AND PREDICTABILITY ON THE COSTS OF VIOLENCE

was virtually no relationship between lethality and violence. The key difference between the N-player game and the two-player game is the possibility of more than one fight in the former. This both mutes the sensitivity of the costs of violence to lethality and raises the overall costs of violence. Also, in the limit as the outcome of fights becomes completely unpredictable, the costs of fighting will rise to the point where all of the surplus associated with winning the prize is competed away. This result is similar to the destruction of surplus that occurs in a variety of preemption games, such as the timing of adoption of a new innovation (Drew Fudenberg and Jean Tirole, 1991).

II. Guns, Drug Markets, and Violence

We can now use the above model to examine reasons for the doubling of the juvenile homicide rate in the years from 1985 to 1995, in a period when the adult homicide rate declined slightly. The increase in juvenile homicides appears to coincide with two factors (Alfred Blumstein 1995): (i) a dramatic increase in drug distribution by street gangs, particularly crack cocaine, and (ii) a great rise in gun-carrying among juveniles, particularly for those involved in the drug trade. Virtually all of the increase in juvenile homicides over this time period is attributable to a rise in gun-related deaths.

In the notation of our model, the profits of the drug trade increased W (which tends to increase fighting), and the accompanying increase in gun usage increased C or lethality. The standard argument concerning the link between juvenile homicide rates and guns has focused on lethality. It is frequently said that

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[4] If players are risk-averse, then this result will be attenuated.

juveniles have always fought, but now they die because they fight with guns. As the model above makes clear, that argument is potentially flawed because it ignores the fact that more lethal weapons should lead participants to show greater discretion in their willingness to fight. Had there been a very lethal fighting technology adopted, but one for which the outcome was nonetheless highly predictable (e.g., the winner of a fight is first determined through fisticuffs, and then the loser is immediately executed), the number of violent deaths is unlikely to have increased so dramatically.

Our model suggests that the standard explanation for the link between guns and juvenile violence is inadequate because it ignores a critical factor: the unpredictability of dispute outcomes when juveniles arm themselves with guns. When fights involve less lethal weapons such as knives, observable factors (e.g., the physical appearance of the opponent, past fighting record, or number of people in the opposing gang) provide a good indicator of who will win the fight. With the introduction of guns, however, the factors that predict victory (e.g., lack of respect for human life, disutility of going to prison, high discount rate) are less observable, more variable over time, and subject to strategic manipulation. Guns are an equalizing force that makes the outcome of any particular conflict difficult to predict. All else held constant, this increases the willingness to fight among weaker combatants, leading to greater levels of violence.

III. Conclusions

This paper has examined violence as a mechanism for allocating scarce resources in a nonmarket setting. We demonstrate that the efficiency with which resources are allocated in that context are strongly positively related to the predictability of fight outcomes. The lethality of the weapons used, in contrast, has an indeterminate impact on the costs of violence, except at very low or very high levels of lethality. Our results suggest that the observed link between guns and homicide rates may not be primarily attributable to the lethality of guns, but rather to the lack of *ex ante* predictability of the winner when guns are involved in a fight. To paraphrase an often heard statement, "guns don't kill people, the unpredictability of guns kills people."

Three limitations to the arguments presented in this paper are important to emphasize. First, the model presented is directly relevant only to disputes over scarce resources carried out by rational actors. Many violent deaths are the result of arguments between spouses or as a consequence of suicide. In such circumstances, the strategic aspects that are central to the model of this paper may be less applicable. Second, we do not consider costs of violence that are external to the disputants. The introduction of guns may lead to the death of innocent bystanders caught in the cross-fire. Finally, our model does not attempt to explain what mechanism for dispute resolution is adopted. Given that the mechanisms used appear to vary substantially across time and space, endogenizing that choice would appear to be a useful extension of the current model.

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