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A Theoretical Investigation of Handguns, Cops and Robbers

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Abstract. We study a theoretical general equilibrium environment in which the only activity of interest is armed robbery. Agents choose whether to be citizens or robbers, and whether to purchase handguns. Armed citizens can protect themselves from robbery but any armed agent runs the risk of accidentally shooting himself or another agent. The government chooses a gun tax, and the intensity of police efforts to arrest would-be robbers and citizens who arm for self-defense. Properties of an equilibrium are characterized and the model is calibrated and solved. In all cases unique equilibria are obtained. We find that guns are an inefficient way of redistributing wealth, in the sense that social costs are very large relative to actual wealth redistribution. In this model society would be vastly better off if handguns could be eliminated. We do find, however, that handguns substantially deter crime when crime is defined as taking another's wealth by force. Yet handguns cause accidental deaths and resultantly in this model policy-makers confront a fundamental trade-off between property rights and gun deaths.

JEL Classification Numbers: C72, K40, K42.

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I. Introduction

There is a great diversity of state policies regarding citizens' carrying of handguns. In some states (i.e. Texas) there are minimal restrictions except for obvious ones such as gun-carrying by convicted felons. In other states (i.e. Minnesota) it is virtually impossible to carry a handgun for self-protection without running the risk of a stiff fine and/or jail. In recent years, a number of states have changed their policies, often in the direction of more liberal gun possession.[1] Now it seems clear that, when citizens can carry guns for self-protection, the activity of an armed robber is considerably changed. And generally, the expectation is that the presence of armed citizens should be a disincentive to committing some classes of crime such as robbery. On the other hand, there is a view that easier availability of guns may contribute to crime simply by making a criminal technology more readily available (Lott and Mustard, 1997). Of course, when gun ownership increases, there are arguably going to be more accidental deaths.

In the last decade or so there has been a great deal of research on this topic, mostly empirical, and with mixed findings. Some have concluded that gun ownership is a disincentive to crime (Lott, 2000, Lott and Mustard, 1997), and some have concluded that it is not (Duggan, 2001). While there has been a good deal of empirical research, it appears that most of it is hampered by an acute lack of reliable data.[2] No one actually knows how many handguns are privately owned in the United States, who owns them, who carries them on the street, or for what purpose.[3] In addition to poor data, there are vexing econometric problems involving exogeneity, causality and the like. For one

[1] At the time of this writing a bill was before the Minnesota Legislature that would make it substantially easier to carry handguns in the state. However, its chances of passage seem slim.
[2] See Lott and Mustard (1997), Duggan (2001) and the studies cited by these authors.

example, can changes in gun regulation at the state and local level realistically be viewed as exogenous, or are they better viewed as endogenous responses to criminal activity? For another, crime rates and agents' choices regarding gun-carrying are clearly endogenous variables, simultaneously determined; what are the exogenous instruments?

It would seem that such issues of endogeneity and causality are ones in which theory might provide insights. However, while there has been some theoretical research on crime, most of it deals with issues such as the effects of income redistribution, and choice of political systems.[4] None of it deals directly with the issue at hand — that is, an environment in which some agents carry handguns to steal, some carry handguns to protect themselves, and all run the risk of killing themselves and/or others. In this study we model an environment in which the only activity of interest is armed robbery and agents may carry handguns for one of two reasons. First, under some circumstances, carrying a handgun will permit the agent to take another's wealth. Second, an honest citizen may choose to carry a handgun for self-protection in which case, if he encounters a robber, he retains his wealth. By definition, an honest citizen will never rob others, and realistically, carrying a handgun entails some risk of accident, either to the gun carrier or to another agent.

In sum, an agent's problem is simple for there are only two choices: (i) to buy a handgun or not; and, (ii) if (s)he buys a gun, to become a robber or a citizen. In the model environment, handguns are best thought of as a technology that allows (or

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[3] To be sure estimates abound.

[4] An interesting exception to this statement is Imrohoroglu, Merlo, and Rupert (2000) although the focus of their study is quite different from ours. Tangentially related theoretical studies include Chaudri and Geanakoplos (1998), and Roemer (1985, 1998).

prohibits) certain wealth reallocations. Specifically and importantly, no agent has a preference for gun ownership per se.

In our model there is a government that makes three decisions. The first is a flat rate gun tax. The second is a choice of police activity levels. By increasing the number of police, the policy-maker can determine the probability that robbers are apprehended. Finally, there is the decision as to whether honest, but armed, citizens are to be considered as lawbreakers. In the "Texas Environment," agents who carry handguns for self-protection are tolerated and no police activity is dedicated to catching them. In the "Minnesota Environment," gun-carriers who only seek to defend themselves are considered criminals and are sought by the police. Again, there is a continuous choice of police activity levels that determines the probability that these gun-carriers will be apprehended.[5]

II. The Environment

There are two periods, t = 0,1. A continuum of agents is represented by an interval I = [0,1] with measure 1. At t = 0 each agent's wealth $w(i)$ is drawn from W = [$\underline{w}$, $\overline{w}$] with a cumulative distribution function F on W. The density function f of F is assumed to have positive value for all w in W. Without loss of generality, I is ordered from low to high wealth so that we can use w(i)$\in W$ and i$\in I$ interchangeably. All agents are risk-neutral and F is public knowledge. Government has three policies which are publicly announced at t = 0 and cannot be changed. It may levy a tax $G_t > 0$ on gun

[5] The empirical literature typically represents citizens' gun carrying as a zero-one event, based on the presence or lack of "shall issue" laws. We think it is much more realistic to model these policies as continuous choices representing how aggressively the authorities pursue gun-carriers. Obviously, even in

ownership. The before-tax market price of a gun, G_p, is taken as exogenous, and the total price of a gun is $G = G_p + G_t$. Finally, there is a home production technology for guns and using this technology any agent can produce a gun at a cost of G^m. Homemade guns are equally as effective as other guns and are not taxed.[6]

The government also determines two distinct levels of police activity. The first is p, which determines the probability that a would-be robber is arrested. The second is q, which determines the probability that a citizen carrying a handgun for self-protection is arrested.

When any agent is arrested it is assumed that the agent's wealth is reduced to zero. Whether this is a dead-weight loss or a transfer payment does not matter for our purposes because (as discussed later) we do not attempt to quantify the economic costs of police activity or of arrests. However, this simple modeling convention does attempt to stylistically represent the fact that, when an agent is arrested, the penalty that can be imposed is an increasing function of the agent's wealth. Fines can be larger and the opportunity cost of jail time is greater. As will be discussed, the assumption of one hundred percent wealth confiscation upon arrest is immaterial. This could be any positive percentage.

Given a unique realization of wealth, the wealth distribution F, and the policies of government, each agent decides in period 0 to buy a gun or not, and to be a citizen or a robber. These decisions cannot be changed in period 1. By assumption, being a robber

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states with very permissive laws many citizens still choose not to arm themselves. And in states with very strict laws, some citizens still arm themselves for self-defense.

[6] The motivation for this assumption is to put an upper bound on the effective price of handguns that can be achieved via taxation. If this were not done, it would be an optimal policy to simply set a gun tax rate so high that no agent in the economy could afford to purchase a handgun. However, we think that our assumption is quite reasonable. Many handguns are stolen, sold illegally and thus not taxed. A smaller number are produced outside the United States, illegally imported, and not taxed either.

requires gun ownership so that there are only three actions for each agent D = {c, u, a}, where c denotes a robber, u denotes an unarmed citizen, and a denotes an armed citizen.[7] Only pure strategies are considered.

IIa. Random Matching, Police and Gun Accidents

At t = 1 there is random matching among agents. If a robber is matched with an unarmed citizen, there is a wealth transfer to the former from the latter. The robber gets all the wealth of the unarmed citizen and keeps his own. If, on the other hand, a robber meets an armed citizen no wealth transfer occurs. If two citizens meet — whether either or both is armed — there is no wealth transfer. If two criminals meet there is also no wealth transfer.

Let $U_i\left(\left(w_i, d\right), \left(w_j, b\right)\right)$ be the expected period 1 payoff of agent i from a decision $d \in D$ at period 0 when agent i meets agent j whose decision is $b \in D$. Table 1 shows the payoffs at t = 1 from the matching of any two agents, where the row agent has wealth of w_r and the column agent has wealth of w_c.

Any agent carry a handgun runs the risk of a gun accident, with probability g (this probability being known by all agents in period 0). If this occurs, the agent's wealth is reduced to zero. Finally, any time an agent meets another agent who is carrying a gun, he may be accidentally shot with probability e, in which case his wealth is reduced to zero.[8] All agents know probability e in period 0. No moral judgment regarding the value of

[7] In some numerical solutions, we consider the possibility that robbers do not require a handgun but citizens can still acquire a handgun at cost for self-protection. These results are discussed in Footnote 27.
[8] If two armed agents meet, then the probability that both are killed is e^2.

human life is intended by this modeling choice. Our thinking is that wealth is related to productivity and thus to the opportunity cost of removing an individual from society.[9]

IIb. An Agent's Problem

Each agent's action at t = 0 is based on his wealth w_i, the wealth distribution F, the market price of a gun G_p, the government policy variables G_t, p, and q, the probability of a gun accident g, and the probability of an accidental shooting e.[10] In addition, it is based on his belief about other agents' actions. A belief of an agent i is a measurable function $b_i = w \to D$.

Under agent i's belief b_i, agent i expects agent j to choose $b_i(w_j) \in D$. Then with b_i, agent i expects

$U_i((w_i, d), (w_j, b)) = U_i((w_i, d), (w_j, b_i(w_j)))$ for all $w_j \in W$.

Let $p_i(d; w_i, b_i)$ be the expected payoff at t = 1 when agent i with w_i and b_i chooses d at t = 0. Then

$$p_i(d; w_i, b_i) = \int_{\underline{w}}^{\overline{w}} U_i((w_i, d), (w_j, b_i(w_j))) dF(w_i). \tag{1}$$

[9] As shown in Table 1 our convention is that all random meetings occur simultaneously. Each agent meets another agent for sure, may (not) meet a police officer and may (not) simultaneously have a gun accident. By further assumption, a robber that either has a gun accident, meets police, or both, loses all wealth. Logically, a self-inflicted gun accident (probability g) and a gun accident inflicted by another (probability e) cannot be simultaneous occurrences. Therefore, without loss of generality we assume that the self-inflicted accident, if it occurs, occurs first.

[10] The value of e only matters to an agent because it affects the probability that he will survive. If he accidentally kills another agent his utility is not affected. Thus accidental shootings are an externality in the usual sense.

Agent i maximizes (1) by choosing an action in D. Denote agent i's best action as $d_i^*\left(w_i, b_i\right)$. Then we can obtain an indirect utility function $V_i(w_i, b_i)$ $=p_i\left(d_i^*\left(w_i b_i\right); w_i, b_i\right)$.

III. Equilibrium

We focus on 'symmetric equilibria' in which agents with the same wealth have the same optimal action. Given government policies, an equilibrium consists of common beliefs on other agents' optimal actions. Every agent's belief is the same, $b_i = b$ for all i. And for all $i \in I$, i's optimal choice coincides with the decision from a common belief, $d_i^*\left(w_i, b\right) = b\left(w_i\right)$.

In this section, we demonstrate that any "interesting" equilibrium of this economy must exhibit certain features. Here and throughout by an "interesting" equilibrium we mean one in which there is at least some criminal activity. We will show that for well-defined wealth ranges, all agents within a range will find it optimal to choose the same action. This results in a great deal of symmetry and excludes a variety of possible equilibria. In general, when there are criminals they will all be poor agents, and when there are armed citizens, they will all be rich agents. There *must* be some unarmed citizens in any "interesting" equilibrium, and these agents will come from a middle wealth range.

In an arbitrary equilibrium, define f_1 be the fraction of agents who in period 0 have chosen to be robbers and f_2 be the fraction who have chosen to be unarmed

citizens. Then ϕ_3 is the fraction of armed citizens in this equilibrium with $f_1 + f_2 + f_3 = 1$. Let E_u be the total wealth of unarmed citizens. By our definition of equilibrium, all agents share common beliefs about ϕ_1, ϕ_2, ϕ_3 and E_u, and each agent takes these values as parametric. Finally, in what follows we assume that the arrest probability for robbers is strictly positive, p > 0, greater than the arrest probability for armed citizens, p > q, and that the gun price is strictly positive, $G_p > 0$.[11]

We can now compute the expected wealth of an arbitrary agent i, resulting from each of the three possible strategies. Given a belief ϕ denote the expected (period 1) wealth of i with initial wealth $w_i \in [0, \infty)$ as $p(d, w_i)$ for each $d \in D = \{c, u, a\}$. Then:

$$p(c, w_i) = (1 - p - g)\{(1 - e + ef_2)(w - G) + Eu\},$$

$$p(u, w_i) = (f_2 + (1 - e) f_3) w_i,$$

$$p(a, w_i) = (1 - q - g)(1 - e + ef_2)(w_i - G).$$

From this extension of the expected wealth function from $W = [\underline{w}, \overline{w}]$ to $[0, \infty)$, we get the following observations.

Observations:

$p(d, \square)$ is linear in wealth for all $d \in D$, (O.1)

$p(c, \square)$ has a higher slope than $p(a, \square)$ since p>q, and, (O.2)

[11] If q ≥ p, being a robber strictly dominates being an armed citizen for any wealth level and thus there can never be armed citizens in equilibrium. We do not want to preclude by assumption the possible existence of armed citizens in an equilibrium.

$$p\left(c,0\right)>p\left(u,0\right)=0>p\left(a,0\right). \tag{O.3}$$

As noted, we are only interested in equilibria in which there is at least some criminal activity or $\phi_1 > 0$, and Condition (2) below is sufficient for that to be true.

$$\underline{w}<\frac{1-\left(p+g\right)}{p+g}\left(\mathrm{E}-G\right), \tag{2}$$

where E is the total initial wealth of the entire population.

Lemma 1 Under condition (2), $f_1 > 0$.

Proof.

Suppose $f_1 = 0$.

Then $p\left(u,w_i\right)=\left(1-ef_3\right)w_i$ and $p\left(a,w_i\right)=\left(1-q-g\right)\left(1-ef_3\right)\left(w_i-G\right)$ for all $w_i \in \left[0,\infty\right)$. Thus, a is dominated by u for all w_i.

Thus, $f_3 = 0$, i.e., $f_2 = 1$.

Then, $p\left(c,w_i\right)=\left(1-p-g\right)\left(w_i-G+E\right)$ for $w_i \in \left[0,\infty\right)$ since $E = Eu$.

Find $w_0 \in \left[0,\infty\right)$ such that $p\left(c,w_0\right)=p\left(u,w_0\right)$, i.e., $\left(1-p-g\right)\left(w_0-G+E\right)=w_0$ or $w_0=\frac{1-\left(p+g\right)}{p+g}\left(E-G\right)$.

By condition (2), for all $w_i \in \left[\underline{w},w_0\right)$,

$w_i<\frac{1-\left(p+g\right)}{p+g}\left(E-G\right)$ or $\left(1-p-g\right)\left(w_i-G+E\right)>w_i$, i.e., $p\left(c,w_i\right)>p\left(u,w_i\right)$.

Thus, $f_2 \neq 1$, which is a contradiction. ■

The next step is to prove that in any "interesting" equilibrium ($\phi_1 > 0$), there must be at least some unarmed citizens ($\phi_2 > 0$). This is Theorem 1,which is proved below.

Theorem 1. $f_1 > 0 \Rightarrow f_2 > 0$.

Proof.

Suppose $f_2 = 0$.

Then $p\left(c, w_i\right) = \left(1 - p - g\right)\left(1 - e\right)\left(w_i - G\right)$ and

$p\left(a, w_i\right) = \left(1 - q - g\right)\left(1 - e\right)\left(w_i - G\right)$ for $w_i \in \left[0, \infty\right)$.

Since $p > q$, $p\left(c, w_i\right) < p\left(a, w_i\right)$ for $w_i \in \left[0, \infty\right)$.

Thus, $f_1 = 0$. ■

In common sense terms, being a robber is a risky business due to the chances of being caught by the police. There can be no reason to run this risk unless there is some potential benefit — meaning someone to rob. Thus, any equilibrium with criminals and police must be an equilibrium with unarmed citizens, too.

Since the two return functions from c and u are linear functions with different y-intercepts, we can get more mileage from Theorem 1. Roughly speaking, two straight lines must cross each other with the intersection in an interior point in W. Otherwise, there cannot be coexistence of criminals and victims as in Theorem 1. Figure 1 shows

this situation graphically. In particular, we can observe that being an unarmed citizen is dominated by being a criminal over some low wealth range $w \in [\underline{w}, v_1]$, and for some high wealth range $w \in [v_1, \overline{w}]$ the ordering is reversed. Furthermore, it is clear that if agent i prefers u to c, then any other agent with higher wealth also prefers u to c. This monotonicity in preferences can be applied to any pair of straight lines. Theorem 2 below gives the final result: in "interesting" equilibria criminal agents will compose a continuous subset of the poorest agents in the economy.

Theorem 2: In any equilibrium with criminal activity, $f_1 > 0$, the agents who become criminals are a continuous (in wealth) subset of the poorest agents in the economy.

Proof.

We propose that the set of criminals is $[\underline{w}, v_1]$.

Since being a criminal is dominated by being an unarmed citizen for $w_i \in (v_1, \overline{w}]$, it suffices to show that for $w_i \in [\underline{w}, v_1]$, c is the best decision.

Suppose to the contrary that there is some $v \in [\underline{w}, v_1]$ such that a is preferred to c. Then a is preferred to c for all $w_i \in (v, \overline{w}]$ by the above monotonicity. Thus $\phi_2 = 0$, which is of course a contradiction to Theorem 1.

We next turn to the rich agents in the economy. Figure 2 portrays the case in which there are armed citizens in an equilibrium. This may be the case, but need not be for "interesting" equilibria may be composed strictly of criminals and unarmed citizens.

Theorem 3: In any equilibrium with armed citizens, they must comprise a continuous (in wealth) subset of all the richest agents in the economy.

Proof.

The existence of armed citizens in an interesting equilibrium means that there is an intersection point v_2 between the two return function lines for u and a. This v_2 should be an interior point of W. If this point v_2 is less than v_1 there are no armed citizens, which is a contradiction. Thus, we have $v_1 < v_2 < \bar{w}$. Furthermore, from the linearity of the two functions, u is dominated by a for $w_i \in [v_2, \bar{w}]$ and a is dominated by u for $w_i \in [\underline{w}, v_2)$. Since c is dominated by u and thus by a for $w_i \in [v_2, \bar{w}]$, a is the best decision for $w_i \in [v_2, \bar{w}]$.

To summarize, as shown in Figure 2 for initial wealth between $\underline{w}$ and v_1 all agents are robbers. For initial wealth between v_1 and v_2 all agents are unarmed citizens. And for initial wealth between v_2 and $\bar{w}$ all agents are armed citizens. As already noted and proved in Lemma 2 in the Appendix, there need not be any armed citizens in an equilibrium with criminal activity. However, there must be at least some unarmed citizens. Note that these results simplify the analysis enormously, since no other equilibria with criminal activity can exist.

IV. Numerical Solutions

In this section we present some numerical solutions, calibrating the model parameters to real world data. Our first objective is to determine if, for reasonable parameter values, there are multiple equilibria (which is entirely possible theoretically). We find that for every combination of reasonable parameters examined, the model's equilibrium is unique.[12]

The second objective is to conduct simple experiments in which the policy variables G_p, p and q are varied. We do not try to determine optimal policies or to fully represent social costs and benefits. In particular, we do not attempt to actually calibrate the cost of a police force. In the model, police activities are represented by the two arrest probabilities, p and q. Meaningfully relating these parameters to real world data on police expenditures would be difficult and would amount to an empirical study in its own right. Similarly, we do not attempt to quantify the economic cost of jail time served by arrested robbers. In the model, the private cost to each agent arrested is total loss of wealth[13]. However, the model does produce solution values for the crime rate and the gun accident rate. Both of these are well-defined and can, we think, be meaningfully related to real world data. As will be seen, even with these limitations the calibration results have several interesting implications.

For simulation purposes, we need estimates of the parameters G_p, g and e, and a density function f(w) for wealth. For simplicity, we assume that wealth is distributed according to a quadratic density function — e.g. a quadratic normalized so as to integrate

[12] We solve numerically using Mathematica for all roots and then check appropriate criteria to determine if they are acceptable equilibria. Thus if there did exist multiple equilibria we would surely find them. Also note that by arbitrarily choosing parameter values, it is easy to produce multiple equilibria.

[13] This cost assumption is admittedly unrealistically, and probably unrealistically high, at least on average. We will discuss this issue further in the next section.

to one. Thus, the density function is f(w) = $\frac{6}{(\bar{w}-\underline{w})^3}(\bar{w}-w)(w-\underline{w})$. This density function has the advantage of simplicity relative to other possible symmetric density functions that concentrate their mass "in the middle". Also, it is bounded above and below which is consistent with our model and realistic for a wealth distribution.

We fit the density function f(w) to actual per-capita wealth data for the United States (Budria, Diaz-Gimenez, Quadrini and Rios-Roll, 2002, Table 26) by first sorting the data into quintiles and then minimizing the sum of squared errors around the function f(w). We imposed a lower bound of w ≥ $1000.[14] The fitted upper bound on the wealth distribution (the only remaining free parameter) was $381,000 and with this value mean wealth according to the fitted function was very close to the actual mean of $191,000. Not surprisingly, the actual data are significantly skewed to the right, having a long tail that is cut off by our quadratic approximation.[15]

Next, we required estimates of the three exogenous parameters G_p, the price of a gun, g, the probability that a gun- carrier accidentally shoots him/her self, and e, the probability that (s)he accidentally shoots another agent. G_p was set at $350 based on trips to several local gun stores.

Estimating gun accident rates is much more challenging. There were 34,040 gun deaths in the United States in 1996 (U.S. Department of Justice website).[16] Although

[14] A positive lower bound on wealth is reasonable and we needed some ability to tax gun purchases without driving any agent's net wealth negative.
[15] Actually, we can choose the upper bound on the density function according to two reasonable criteria: one, to match the mean of the actual data; and two, to minimize the sum of squared errors. Both methods produce very similar estimates.
[16] This number includes suicides and homicides as well as what are called "unintentional deaths." In recent years the rate of gun deaths has been declining in the United Sates. However, it still remains high, especially compared with other developed countries. Fajnzylber, Lederman, and Loayza (2002b) report

there are many estimates, no one actually knows how many handguns are privately owned in the United States. One estimate is that there are about 65 million privately owned handguns (Brady Campaign Website), and this number is supported by Bureau of Justice estimates that about 77 million handguns were produced in this country between 1899 and 1993.[17] Assuming arbitrarily that twenty-five percent of these private handguns are actually carried on the streets gives an estimate of about thirteen million carried handguns, nationwide. Then, the probability that a gun carrier will shoot himself or another agent can be estimated as 34,040 / 16,000,000 = .26%. If we further assume that either event is equi-probable then we have the estimates g = e = .13%.[18] Obviously, these estimates of e and g are extremely imprecise. However, we will show that when we increase or decrease g and e by a *factor of ten*, no qualitative conclusion is affected.

Finally, we needed to choose appropriate ranges for the three policy variables G_t, p and q. G_t is allowed to vary between zero and $650, the latter representing a tax rate of about 217 percent. We assume that at any higher gun tax rate, home production of guns kicks in, or that G^m = $1000.[19] The probability p that a robber will be arrested was allowed to vary between 20 and 40 percent, and the probability q that an armed citizen will be arrested between zero and 20 percent.[20] These ranges for p and q are admittedly

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that the U.S. had the seventh highest rate of homicides out of a group of 39 countries. Higher than U.S. homicide rates were reported for Brazil, Colombia, Mexico, The Philippines, Thailand, and Venezuela.

[17] The depreciation and destruction rate of handguns is very low, and an old handgun can still function perfectly. About ten percent of handguns in the U.S. are imported from other countries. (Bureau of Justice website).

[18] These estimates of g and e are clearly biased upward by assuming that all gun accidents involve individuals carrying handguns for robbery or self-protection. Clearly that is not the case (hunters have accidents, too.) On the other hand, our conversations with local police officials suggested that, based on their experience, we are significantly under-estimating the number of handguns actually being carried on the street.

[19] Recall that we did not want to allow a total gun price exceeding the wealth endowment of the poorest agent which for present purposes is $1000.

[20] We only looked at examples in which q < p. When q > p, there will never be armed citizens in

arbitrary.[21] Notice, however, that in the model with risk neutral agents all that matters is their expected cost of being arrested. This depends not only on the probability of arrest, but also on the assumption that arrest results in confiscation of all wealth, the greatest penalty that can be imposed theoretically. This "maximum-penalty" assumption is surely not correct, and an implication is that assumed arrest probabilities couldn't be taken literally.[22] The best we can do therefore is to vary p and q over as wide a range as possible.[23]

IVa Results of Numerical Experiments

Table 2 shows the results of varying the gun tax G_t between zero and $650, holding other policy variables constant, and holding parameters fixed at their base-case levels of G_p = $350 and g = e =.13 percent. We assume p = 30 percent and q = 0 so this is the "Texas Environment" in which no attempt is made to deter agents from arming for self-protection. Notice, first, that as G_t increases arrest rates increase monotonically. Also, some armed citizens respond as expected by disarmed; thus, as G_t increases from zero to $650, the fraction of armed citizens in the economy declines from about 87 to about 83 percent. However, the response of robbers is "perverse". As G_t increases, some unarmed citizens change over to robbers and the fraction of robbers in the economy

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equilibrium — just robbers and unarmed citizens. This is because when q > p being a criminal strictly dominates being an armed citizen for any wealth level.

[21] There exist data on crime rates and on arrest rates by category of crime. However, these data are not useful for estimating the variable p in the model. That is because, in the model, robbers are defined by intent, not by outcome and are composed of two classes. There are robbers that are successful (and thus would be included in crime rate statistics) and those that want to rob but can't because they are frustrated by armed citizens.

[22] For example, if the police confiscate 100 percent of wealth, as we assume, and the probability of arrest is .2, then the expected cost of arrest to the criminal is .2w. However, if the confiscation rate is 50 percent and the probability of arrest is .4, the expected cost is still (.5)*(.4)*w = .2w.

increases from about .53% to about 1.07%. With more robbers and less armed citizens, the crime rate must increase and it does, nearly tripling. The fraction of unarmed citizens in the economy rises monotonically with G_t, from about 12.8 percent to about 15.9 percent. Resultantly, the rate of gun accidents falls monotonically (but slightly). In sum, increases in G_t result in both a social cost (rising crime) and a social benefit (declining gun deaths).

Table 3 shows the results of varying p, the arrest rate of criminals, with all parameters at their base case values and setting q = 0 (the "Texas Environment"). As p rises, the arrest rate increases monotonically. The fraction of robbers in the economy falls from .6% to .47%. However, the fraction of armed citizens falls much faster, from 90.1% to 82.9%. Thus, as p increases the crime rate "perversely" rises from about .06% to about .08%. The fraction of unarmed citizens in the economy increases with the result that the gun accident rate falls from about .24% to about .23%. Therefore, as with increasing gun taxes, increasing police activity, p, is not an effective way of deterring robbery; however, it does help to reduce accidental deaths.

Table 4 shows the results of allowing the arrest rate of armed citizens to vary between zero and 20%, with the parameters fixed at the base case and p = 30%. Thus we are looking at the "Minnesota Environment." As q increases, the percentage of armed citizens in the economy falls rapidly (as presumably intended), from about 86.7% to 67.3%. However, the percentage of robbers also increases markedly, from .53% to 20.3%. Not surprisingly, the crime rate is monotonically increasing in q, as is the total wealth transfer to robbers.

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[23] We tried diligently to obtain analytical results before going to numerical procedures. However, the conditions for equilibria consist not only of simultaneous equations, but also of inequality constraints, and

In this example, several of the social indicators are non-monotonic in the level of q. For example, the value of q that minimizes gun deaths is somewhere around 10%. Thus, from a policy perspective there would be no reason to ever raise q higher than (about) 10% since that would increase the crime rate, the gun accident rate, and spending on police. Finally, note that in the previous two examples, the fraction of robbers in the economy is never large, hardly more than 1%. However, with sufficiently high values of q, crime blossoms and at q = .2 more than 20% of agents in the economy have become robbers.

IVb. Common Features of the Numerical Experiments

The three experiments we have presented share several common features. First, in all cases the equilibrium rate of gun ownership appears to be unrealistically high (over 80 percent), and this is primarily due to a large fraction of armed citizens. There are several possible explanations. One is that agents (especially the rich) have non-pecuniary distaste for gun-ownership that is not represented in our model. Relatedly, if we allowed for risk-aversion, agents would probably be less willing to accept the risk of extreme losses due to gun accidents.[24]

The second common feature of the examples is that guns are a remarkably inefficient mechanism for wealth re-distribution. In Table 2, for example, the largest wealth re-distribution occurs when G_t = \$650. In that case, the crime revenue lost by victims is about .06% of initial social wealth. Of that total, criminals only get to keep

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the combination of the two, while not mathematically challenging, is very tedious to solve.

about .043% of initial social wealth (not shown), after deducting for their losses due to arrest and accidental death. The total deadweight loss in this equilibrium (gun accidents plus gun purchases) is .38% of initial wealth — or about nine times the net wealth transfer. This deadweight loss computation is surely order-of-magnitude too small, for it does not include the cost of police and the lost output due to jail sentences.

The transfer-efficiency computations for the Table 3 examples are not presented but are even bleaker than those for Table 2. In table 4, however, with q = .2 the net wealth transfer due to robberies becomes much larger at 1.21% of initial wealth (not shown), and also relative to deadweight losses (gun accidents plus gun purchases) of .37%. Thus, robbery may appear to be a more "efficient" method of wealth transfer in this example. However, this can hardly be viewed as socially desirable equilibrium. Crime is high and about 20 percent of the population are robbers. Gun deaths are relatively low, but only because about 19.6% of the population is in jail.

Finally, to illustrate the trade-off confronting the policy-maker, Table 5 compares two extreme policies. In the first, all government interventions are at very high levels. The gun tax is G_t = \$650, robbers' probability of arrest is p = .5, and armed citizens' probability of arrest is q = .3. This is the "Maximum Intervention Policy". The second is a sort of "Wild West Policy" in which there is minimal government intervention with G_t = 0, p = .2 and q = 0.[25] All parameters are at the base case values.

Under the maximum intervention policy, would-be robbers constitute about 30.4% of the population, and about 26.7% of the population is in jail. However, the gun

[24] Of course, a third possible explanation is that there are simply more armed citizens than most observers believe.
[25] Recall that we cannot set p "too low" and still get an equilibrium with both criminals and unarmed citizens.

death rate is a relatively low .15%. By contrast, under the laissez faire policy, only about .6% of agents are would-be robbers and .12% are jailed. However, the gun accident rate is a relatively high .24%. In sum, there is either a high crime rate and a low gun death rate, or vice versa. This is a feature of all the numerical experiments we have conducted including many that are not reproduced in this paper.

IVc. Robustness

All our results are qualitatively robust to wide variations in the parameter assumptions. In Table 6 we compare the Maximum Intervention Policy and the Wild West Policy, while radically varying the parameter assumptions. In these robustness tests we do not bother to experiment with the gun price G_p simply because there is little room to do so. As discussed earlier, we cannot allow for gun prices greater than $1000 and we obviously do not want to consider negative gun prices. The remaining parameters are the gun accident probabilities, e and g, and parameters of the wealth distribution, f(w).

First in Table 6 we radically decrease both e and g, setting them at ten percent of the base case value. This primarily affects the equilibrium gun accident rate, which changes roughly proportionally to the changes in e and g. The crime rate also declines with e and g, but the effect is much smaller. Similarly, when we increase both e and g by a factor of ten there is a large, roughly proportional, effect on the accident rate and a much smaller effect on the crime rate. In both cases, however, the results of the preceding analysis are qualitatively unaffected. That is, the Maximum Intervention

Policy results in high crime and low gun death rates, whereas the Wild West Policy results in low crime and high gun death rates.[26]

Finally, in Table 6 we assume that the bounds of the wealth distribution are shifted inward by about 37% — in effect, eliminating some of the extreme rich agents in the economy and some of the extreme poor. Perhaps surprisingly, the equilibrium is not too greatly affected under either policy scenario. In both cases, the gun accident rate falls but the crime rate actually increases.[27] For present purposes, the main point is that our results remain qualitatively unchanged if we substantially "compact" the wealth distribution.[28]

V. Conclusions

The model produces unique equilibria that seem to be reasonable in most respects except that the percentage of armed citizens may be too high. Handguns do appear to deter crime when crime is defined as taking another's wealth by force. And, based on the

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[26] The same conclusions obtain when we vary g and e separately. Actually, changing e by itself does not affect the solutions much. That is because e is an external cost to each individual agent and does not enter directly in his/her objective function.

[27] We experimented with an environment in which robbers did not require a handgun to rob, but citizens could acquire a handgun at cost for self-protection. In all parameterizations, this resulted in a slightly higher fraction of robbers (as would be expected), but no other significant changes. All qualitative results were unaffected.

We also experimented with a different wealth distribution to reflect the fact that typically not all one's wealth is at risk in a robbery. (We thank Andy McLennan for this suggestion). In this case, the poorest agent in the economy is endowed with (just) the price of a handgun and the richest agent with $20,000. Not surprisingly, the equilibrium fraction of armed citizens declines substantially from the base case, because there are fewer citizens with enough wealth to make it worthwhile to arm. At the same time, the equilibrium fraction of robbers rises. However, no qualitative conclusions are affected. As with the previous wealth distribution, the crime rate (accidental death rate) is an increasing (decreasing) function of the arrest rate for robbers (p). And also as before, the crime rate is an increasing function of the arrest rate of armed citizens (q). The accidental death rate is now minimized when q is about five percent, as opposed to about ten percent in Table 4. We would be glad to provide results of all these experiments to any interested reader.

[28] Obviously, we cannot significantly spread the wealth distribution to further check for robustness. As discussed earlier, if we reduce the lower bound of f(w) by any significant amount, some poor agents cannot afford to buy handguns.

calibrated solutions, this deterrence effect can be very large. However, guns cause accidents and policies that reduce the accidental death (crime) rate increase the crime (accidental death) rate. The only exception to this statement is the arrest rate of armed citizens, q. If q is increased beyond about ten percent, both the crime rate and the accidental death appear to increase in q. Obviously, there would never be a reason to increase q beyond that value. In sum, in this model policy-makers unavoidably confront a fundamental trade-off between property rights and accidental death. All these conclusions are robust to wide variations in parameter assumptions.

It appears that investigating this problem in general equilibrium could provide guidance for future empirical work. Indirect (induced) responses to policy changes are often larger than direct effects. For example, suppose that the objective is to reduce the crime rate and the policy is to increase the probability, p, that a robber will be arrested. The examples show that as p increases the fraction of robbers in the economy declines as would be expected, but the fraction of armed citizens declines faster. Thus, as p rises there are fewer robbers but more robberies because the average robber has a higher success rate.[29] Our model also makes a strong prediction that is empirically testable: handgun ownership should be concentrated in the richest and poorest segments of society. Unfortunately, we have so far been unable to find any existing empirical evidence on handgun ownership by wealth or income levels.

Finally, our results strongly suggest that if handguns could be abolished, society would be better off (abstracting from non-pecuniary preferences). Handguns appear to be

[29] This raises an interesting question as to the economic definition of "crime:" Should it be based on intent, or on outcomes? The general equilibrium model captures both variables whereas published crime statistics only include the latter.

a remarkably inefficient mechanism for reallocating wealth, in the sense that related social losses dwarf the actual wealth transfer handguns effectuate.

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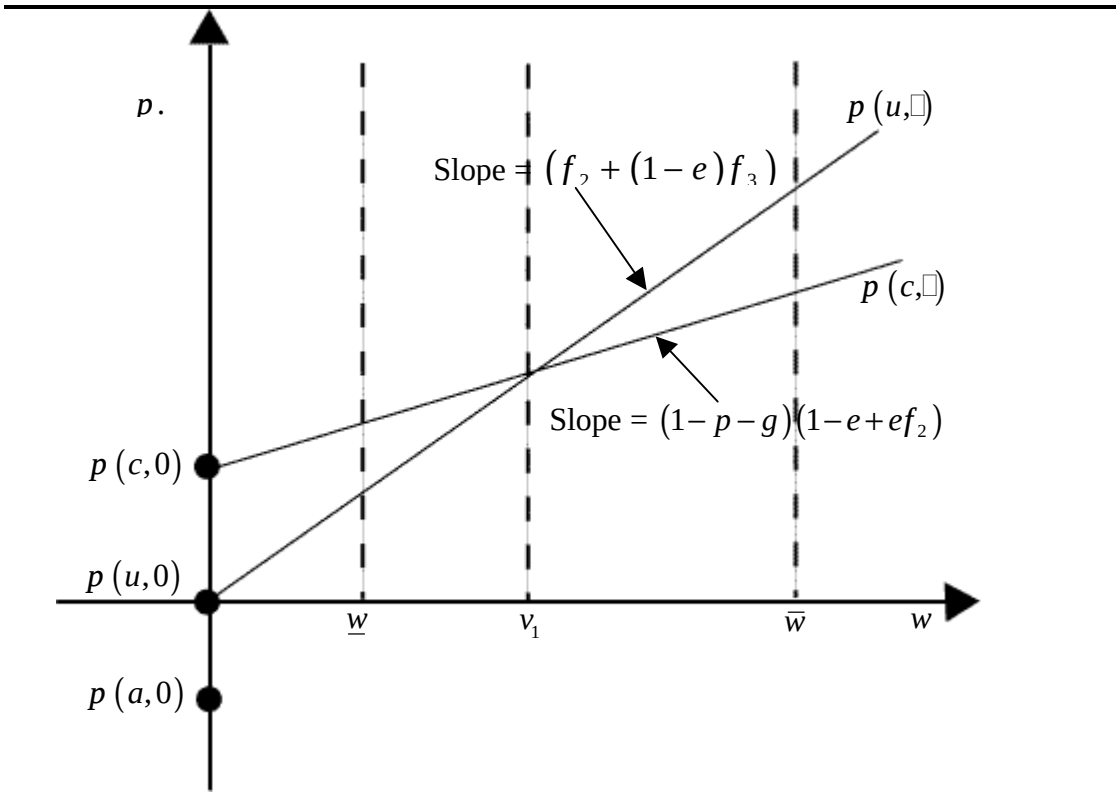
Figure 1*

Wealth Ranges where it is Optimal to be a Criminal (Unarmed Citizen)

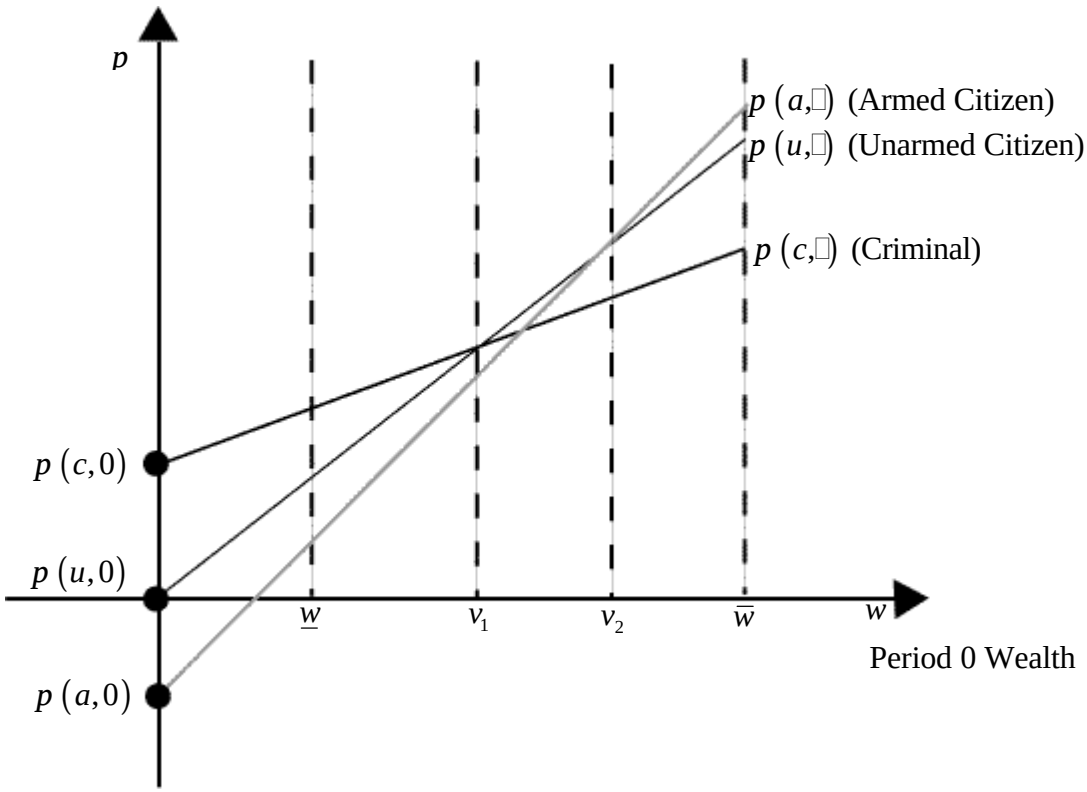


***Notes**

1. Being a criminal is dominated by being an unarmed citizen for $w_i \in (v_1, \overline{w}]$.
2. Being an unarmed citizen is dominated by being a criminal for $w_i \in [\underline{w}, v_1)$.

Figure 2

Expected Return (Period 1 Wealth) to three Different Strategies*



* Over the wealth range $\underline{w} - v_1$ it pays to be a criminal. Over the wealth range $v_1 - v_2$ it pays to be an unarmed citizen. Over the wealth range $v_2 - \overline{w}$ it pays to be an armed citizen.

Appendix

The following lemma presents a necessary and sufficient condition for the existence of armed citizens in an equilibrium.

Lemma 2: $f_3 > 0$ *iff* $p\left(a, \overline{w}\right) > p\left(u, \overline{w}\right)$.

Proof:

(Only if) Suppose not, $p\left(a \quad \overline{w}\right) \quad p\left(u \quad \overline{w}\right)$

$\left(1 \quad p \quad g\right)\left(1 \quad e \quad e \quad \right)\left(\overline{w} \quad G\right) \quad \left(\quad \left(1 \quad e\right) \quad \right)\overline{w}$. Then

$\left(\; - \quad - \quad \right)\left(\; - \quad + \quad f_2\right) \quad \geq \left\{\left(\; - \quad - \quad \right)\left(\; - \quad + \quad f_2\right) - \left(f_2 + \left(\; - \quad \right) f_3\right)\right\}^{-}$.

$\left(1-q-g\right)\left(1-e+e \quad {}_2\right)G > \left\{\left(1-q-g\right)\left(1-e+e \quad {}_2\right) - \left(\quad {}_2 + \left(1-e\right) \quad {}_3\right)\right\} w_i$ for all

$w_i \in \left[\underline{w}, \overline{w}\right)$.

Then $\left(1-q-g\right)\left(1-e+ef_2\right)\left(w_i - G\right) < \left(f_2 + \left(1-e\right) f_3\right) w_i$, *i.e.*,

$p\left(a, w_i\right) < p\left(u, w_i\right)$, for $w_i \in \left[\underline{w}, \overline{w}\right)$.

Thus, $f_3 = 0$, which completes the claim. ■

(If)

Suppose $p\left(a, \overline{w}\right) > p\left(u, \overline{w}\right)$.

Since $p\left(a, 0\right) < p\left(u, 0\right)$ and both $p\left(a, \square\right)$ and $p\left(u, \square\right)$ are linear,

by the intermediate value theorem,

there is v_2 with $0 < v_2 < \overline{w}$ such that

(i) $p\left(a, w_i\right) < p\left(u, w_i\right)$ for $w_i \in \left[0, v_2\right)$,

(ii) $p\left(a, v_2\right) = p\left(u, v_2\right)$, and

(iii) $p\left(a, w_i\right) > p\left(u, w_i\right)$ for $w_i \in \left(v_2, \overline{w}\right]$.

By (iii), $f_3 > 0$.

Table 1

Period 1 Expected Payoff to Agent r (row); $U_r\left(\left(w_r,\bullet\right),\left(w_c,\bullet\right)\right)$

who is randomly matched with Agent c (column); $U_c\left(\left(w_c,\bullet\right),\left(w_r,\bullet\right)\right)^{*+}$

Agent O's action / Agent r's action	c:	u:	a:
c:	$(1-e)(1-p-g)(w_r-G)$ $(1-e)(1-p-g)(w_c-G)$	$(1-p-g)(w_r-G+w_c)$ 0	$(1-e)(1-p-g)(w_r-G)$ $(1-e)(1-q-g)(w_c-G)$
u:	0 $(1-p-g)(w_c-G+w_r)$	w_r w_c	$(1-e)w_r$ $(1-q-g)(w_c-G)$
a:	$(1-e)(1-q-g)(w_r-G)$ $(1-e)(1-p-g)(w_c-G)$	$(1-q-g)(w_r-G)$ $(1-e)w_c$	$(1-e)(1-q-g)(w_r-G)$ $(1-e)(1-q-g)(w_c-G)$

* These period 1 expected payoffs reflect the possibility that, before meeting another agent, an armed criminal may (with probability p) meet the police, lose his wealth, and be removed from the population. They also reflect the probability g that any agent who chooses to carry a gun may experience a gun accident. The possibility that it is costly for an armed citizen to meet the police is not considered here. $w_{r(c)}$ denotes the wealth of the row (column) agent. The row agent is listed first, the column agent second.

\+ c denotes a robber; u denotes an unarmed citizen; a denotes an armed citizen.

Table 2.
Numerical Solutions Varying The Gun Tax, G_t *

G, Gun Tax ($1,000)	0	0.25	0.45	0.65
Percentage of Population:				
In Period Zero				
Criminals	0.527512	0.765629	0.944088	1.0729
Unarmed Citizens	12.7841	14.3571	15.3264	15.9496
Armed Citizens	86.6884	84.8773	83.7295	82.9775
In Period One				
Arrested by Police	0.158254	0.229689	0.283226	0.321871
Killed in Gun Accident	0.226454	0.222292	0.219719	0.21806
Wealth loss Due to				
(As % Initial Wealth)				
Gun Accidents	0.237677	0.234292	0.232114	0.230675
Gun Purchase	0.15982	0.156937	0.155161	0.154019
Total Losses	0.397497	0.391229	0.387275	0.384694
Crime Rate in %	0.0674375	0.109922	0.144695	0.171124
Crime Revenue from Victims	0.0210288	0.0369581	0.0508413	0.0618078
(As % Initial Wealth)				

* Parameters are $G_p = 350$, e = g = .13%. $\underline{w} = 1{,}000$, $\overline{w} = 381{,}000$. The fixed (for this example) policy variables are p = .3, and q = 0.

Table 3.
Numerical Solutions Varying p, the Robber's Probability of Arrest*

p, Criminal's Probability of Arrest	0.2	0.25	0.3	0.35	0.4
Percentage of Population					
In Period Zero					
Criminals	0.596789	0.558773	0.527512	0.50068	0.476876
Unarmed Citizens	9.27671	11.0129	12.7841	14.6306	16.5924
Armed Citizens	90.1265	88.4283	86.6884	84.8687	82.9307
In Period One					
Arrested by Police	0.119358	0.139693	0.158254	0.175238	0.190751
Killed in Gun Accident	0.2356	0.231071	0.226454	0.221643	0.216535
Wealth loss Due to					
(As % Initial Wealth)					
Gun Accidents	0.244121	0.240971	0.237677	0.234163	0.230341
Gun Purchase	0.166247	0.163065	0.15982	0.156436	0.152841
Total Losses	0.410368	0.404036	0.397497	0.390599	0.383182
Crime Rate in %	0.0553624	0.0615373	0.0674375	0.0732526	0.0791253
Crime Revenue from Victims	0.0149914	0.017944	0.0210288	0.0243197	0.027895
(As % Initial Wealth)					

* Parameters are $G_p = 350$, e = g = .13%. $\underline{w} = 1{,}000$, $\overline{w} = 381{,}000$. The fixed (for this example) policy variable are $G_t = 0$ and q = 0.

Table 4.
Numerical Solutions Varying q, the Probability that An Armed Citizen is Arrested

q, Armed Citizen's Probability of Arrest	0	0.05	0.1	0.15	0.2
Percentage of Population:					
In Period Zero					
Criminals	0.527512	5.39058	10.3573	15.3381	20.3242
Unarmed Citizens	12.7841	20.7026	20.006	16.8975	12.3413
Armed Citizens	86.6884	73.9068	69.6367	67.7645	67.3345
In Period One					
Arrested	0.158254	5.31251	10.07086	14.76612	19.56417
Killed in Gun Accident	0.226454	0.200591	0.197403	0.199997	0.205488
Wealth loss Due to					
(As % Initial Wealth)					
Gun Accidents	0.237677	0.214936	0.209939	0.209978	0.212483
Gun Purchase	0.15982	0.145309	0.146586	0.152282	0.160631
Total Losses	0.397497	0.360245	0.356525	0.36226	0.373114
Crime Rate in %	0.0674375	1.11599	2.07208	2.59174	2.50827
Crime Revenue from Victims	0.0210288	0.554081	1.19692	1.64225	1.6952
(As % Initial Wealth)					

* Parameters are $G_p = 350$, e = g = .13%. $\underline{w} = 1{,}000$, $\overline{w} = 381{,}000$. The fixed (for this example) policy variable are p = .3, and $G_t = 0$.

Table 5.
Two Scenarios: Maximal and Minimal (Wild West) Government Intervention

Intervention Policy	Maximal		Minimal
p, Criminal's Probability of Arrest	0.5		0.2
q, Armed Citizen's Probability of Arrest	0.3		0
G, Gun Tax	0.65		0
Percentage of Population:			
In Period Zero			
Criminals	30.4432		0.596789
Unarmed Citizens	31.1481		9.27671
Armed Citizens	38.4088		90.1265
In Period One			
Arrested	26.7442		0.119358
Killed in Gun Accident	.1549968		0.2356
Wealth loss Due to			
(As % Initial Wealth):			
Gun Accidents	.166605		0.244121
Gun Purchase	.126168		0.166247
Total Losses	.292773		0.410368
Crime Rate in %	9.48246		0.0553624
Crime Revenue from Victims	8.97345		0.0149914
(As % Initial Wealth)			

- Parameters are $G_p = 350$, e = g = .13%. $\underline{w} = 1{,}000$, $\overline{w} = 381{,}000$.

Table 6.
Robustness Check. Varying e, g and the Wealth Distribution f(w).

	Crime Rate (%)	**Gun Deaths (% of Population)**
Maximal Intervention Policy		
p is .5, q is .3 and G_t is 600.		
e = g = .13% (base case)	9.482	0.167
e = g = .013%	9.426	0.0167
e = g = 1.3%	10.06	1.645
Reduce Spread of Wealth Distribution (*)	10.37	0.16
Wild West Policy		
p is .2, q is 0, gun tax is 0.		
e = g =.13% (base case)	0.055	0.236
e = g = .013%	0.044	0.025
e = g = 1.3%	0.205	2.37
Reduce Spread of Wealth Distribution (*)	0.071	0.223

* In this instance, the lower bound of the wealth distribution is increased from 1 to 71. The upper bound is reduced from 381 to 311. With the symmetric distribution, this obviously leaves the mean of the distribution unchanged. We cannot spread the wealth distribution without driving wealth negative for the poorest agents in the economy. Also, e = g = .13%.