THE DETERRENCE EFFECTS OF GUN LAWS IN GAMES WITH ASYMMETRIC SKILLS AND INFORMATION

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Abstract

This paper presents a game theoretic model of crime and self-defense with gun use. The main purpose is to evaluate gun control policy effectiveness on crime reduction. The effects of agent's information assumption and some extensions such as criminals' first move advantage and different costs and skills on gun carry are studied. The results show that policies that increase the availability of guns take criminals to always carry guns even if they have fight advantage over the victims. The main conclusions are that gun control implies on a decrease of gun crimes and that such policies are more effective when affects both criminals and victims costs.

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JEL classification: K42, C72

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1. Introduction

Guns are a quite efficient coercion tools. It kills in an easier and fast way when compared to other weapons, because they demand little or none force use (Zimring, 1968; Wolfgang, 1995). Besides, when they are used in a confrontation, they reduce the chances of a reaction by the opponent (Cook, 1991), consequently, guns are powerful self-defense tools. Because of these characteristics, guns are frequently used in crimes that involve confrontations. However, in the literature there is not a consensus about the effect of gun availability on crime.

There are at least two opposed arguments well established. Some authors argue that the use of guns in self-defense by victims (placing guns in the "good hands[3]") creates a positive externality due to uncertainty generated to criminals (Kleck and Patterson, 1993; Lott and Mustard, 1997; Lott, 1998; Lott, 2010). This uncertainty would reduce crime (trough deterrence effect) because it would increase the probability of a violent reaction by victims, therefore, it would increase not only the punishment severity but also the probability of punishment, so it would increase the crime costs to potential criminals.

Considering these argument forty eight American states adopt laws that facilitate the access to guns[4]. Of these, thirty nine states adopt laws known as "shall issue laws", that allow any citizen with a minimal age, without mental illness and without criminal records[5] is eligible to obtain a license to buy and to carry a gun. Other nine states adopt laws called "may issue laws", that demand a justification for the use and the permission is conditional to the approval by an authority (Lott, 2010).

There are authors who argue that the increment of guns supply doesn't decrease not only the gun costs to potentials victims, but also reduces it to potentials criminal trough availability effect (Cook, 1991; Cook and Ludwig, 1996, 1998; Dezhbakhsh and Rubin, 2003; Hemenway, 1997; Ludwig, 1998; McDowall, Loftin and Wiersema, 1995). Cook (1991), for instance, argues that criminals will react to an increase in the gun supply, because the perception by them that a victim's probability of gun carry increased will stimulate criminals to carry guns also and, it would increase the violence in crimes[6].

Surprisingly, there is no disagreement that both arguments are plausible, but there is disagreement about which effect is dominant. Unhappily, most of the discussion regarding the gun control is based on empirical works and there are a few theoretical works.

The most known empirical work is Lott and Mustard (1997) that uses the argument of the deterrence effect to justify their results. Although the work has been used by several politicians as argument to defend the right to gun ownership, it is quite criticized by several authors because their methodological problems. The most forceful critique is from Black and Nagin (1998), who affirms that the results obtained by Lott and Mustard are biased due to specification errors in their econometric model. Other critiques can be seen in the works of Ludwig (1998), Duggan (2001), Ayres and Donohue (2003) and Dezhbakhsh and Rubin

[3] Part of these argument is based on the evidence that the most of convicted by gun homicide have previews criminal record, so, they are not enable to get a license do buy guns (Cook and Ludwig, 1996; Kates and Polsby, 2000).

[4] Only the states of Illinois and Wisconsin keep illegal to carry a gun. See Lott (2010) to have a description of these states and their classification.

[5] The legislations are quite different. See Vernick and Hepburn (2003) for a review.

[6] Following Cook (1987) robberies with gun use are three times more deadly than a knife use and ten times more deadly than other tools.

(2003). These authors with the use of other econometric methods and other national databases found insignificant or positive results for guns use in several crime types.

So, many works spend a great effort to criticize methodological problems while theoretical questions are disregarded. Clearly, the discussion lacks of theoretical basis and the empirical did not let clear the result effect of gun availability on crime (Cook and Ludwig, 2006). After all, the decision of obtaining, to carry and to use a gun is not different to several daily situations which the individuals' actions are based on incentives. Then, why not to build theoretical models that consider these incentives?

A theory to evaluate decisions regarding guns should follow some directions given by the stylized facts. For instance, the slogan is old, but it is true that guns don't kill people, people kill people. Therefore, the model should contain assumptions about the individuals' behavior. It is a very important issue on gun use analysis that is recognized by many courts, since they don't give so much importance to arm type on judgments, but give a great importance to the motive (incentive) of the crime.

Another necessary and trivial assumption is that crime with or without guns are risk activities. Not only because there is a risk of legal system punishment, but also because there is a reaction possibility by potential victims. This issue is missed by many theoretic works about crime. Despite that is unclear how frequently guns are used to self-defense it could be perceived by criminals to be more likely to happen than a conviction[7]. The decision of carry a gun to either practice crimes or self-defense purposes should consider reaction possibilities and should have behavioral assumptions about individuals. In this context, game theory is a powerful tool to model these interactions and uncertainties.

Taylor (1995) was the first work to use a game theoretical approach to model crime meetings and gun use. In his model, he assumes that criminals only commit crimes with guns and there is no possibility to have some fatal victim in the meeting between criminals and victims. These assumptions limit the work conclusions, once that a central question relate to gun control is that if it will reduce or not the number of fatal victims.

Mialon and Wiseman (2005) provided a more complete model. Their main conclusion is that the Second Amendment's right to bear arms cannot be revoked without a loss of individual freedom and, for consequence, potential victims have welfare loss. The main limitation of the work is to assume that criminals and victims have the same skills and, then, they have the same chance in a confrontation. This assumption is not realistic, since criminals always surprise (or at least try) their victims and it gives to them a first moving advantage.

The present paper intends to fill some theoretical gaps left by previous studies about the study of the effects of gun availability on crime. For this goal, it presents a game theoretical model of crime and self-defense with many modifications in relation of preceded works. In first place, all forms of information are considered, it means, perfect, imperfect and incomplete. In these models, both arguments found in the literature, deterrence and availability effects are considered.

Besides, the paper presents relevant theoretical differences in relation to the previous literature. In the paper, it is considered that victims and criminals may have an unequal confrontation, because criminals have high skills handling a gun (Kellermann et al., 1993) and they can surprise victims and it gives to them a first mover advantage in the confrontation (Ludwig, 2000; Cook, Moore and Braga, 2002).

[7] Kleck and Gertz (1995) estimated around 2,5 millions of self-defense actions. However, Hemenway (1997) and Cook and Ludwig (1998) conclude that this result is overestimated. The last authors estimate around 100,000 reactions per year. It is more than convictions by gun crimes.

Another important modification is that in this paper the main objective of a confrontation between criminals and victims is not to kill each other. In general, guns are used by criminals to intimidate and to obtain less resistance by victims (Cook, Moore and Braga, 2002). The deaths happen more frequently when the individuals notice that their life is threatened (Wright and Rossi, 1994). It means that criminals as well as victims use guns with the self-defense purpose.

Regarding this ideas, the paper analyzes the effect of gun control on crime. The main purpose is to discuss how laws that affect the guns supply (control over production, transactions, carry and use; taxation) and the guns demand (punishment for crimes with guns) influence the crime. The paper is organized as follows, after this brief introduction, the next section formally presents the game theoretical models under different assumptions over information. In the end of the paper some conclusions are presented as well as some policy suggestions to crime reduction.

2. Game theoretical models of crime and self-defense

Initially this section presents the basic assumptions considered in the models. Many of them will be relaxed later. The population is divided in two groups: potential victims and potentials criminals. All potential victims and potential criminals are identical, but victims can have different gun skills. In the game, the victims have an endowment $w>0$ and criminals do not have any endowment, but they can get one through a crime.

The possible set of strategies to the potential criminals are: they could choose to not commit a crime (- C), choose to commit a crime without a gun (- GC) or choose to commit a crime with a gun (GC). The set of possible strategies to the potential victims are: go to street without a gun (- G), go to street carrying a gun with the self-defense objective (G). Initially is considered that victims and criminals have the same cost[8] $g>0$ to carry a gun and that both can die in a confrontation with a cost $d>0$. This assumption will be relaxed in the static model with imperfect information. Further on the strategy of not go out to street (lying low) the will be added to these initial assumptions.

2.1. Dynamic models with perfect and imperfect information with pure strategies equilibrium

Criminals can select their victims and can choose the best moment to commit a crime (McDowall, Loftin and Wiersema, 1994). It has an important implication in the success rate of gun use with self-defense purpose, since the success is conditioned to the capacity to use the gun without incurring in a preventive attack by the opponent. So, the definitions if the actions are sequential or simultaneous are relevant to determine the result of confrontation (Cook, 1991).

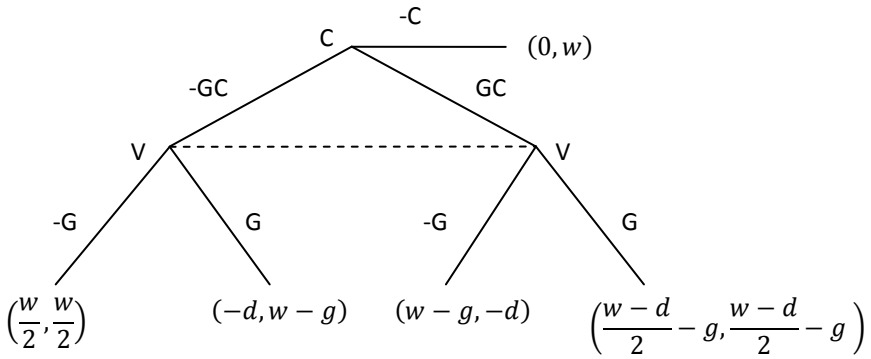
In this section, two possibilities about the information are considered. With perfect information actions are sequential, then the game sequence is: criminal decides to commit a crime or not, if he chooses the crime option, he decides to use a gun or not. Victim play at third stage and know all game history, so he decides to use gun or not. So there are at least

[8] In this case, g includes all monetary costs associated to buying, carrying and using a gun.

two stages where criminals have first mover advantage[9]. With imperfect information, the game has only one stage and decisions are simultaneous and, consequently, there is not asymmetry.

The payoffs are presented in the figure 1. In this game, it is assumed that criminals and victims have the same skill in gun use, so the payoffs are equal to Mialon and Wiseman (2005).

Figure 1 Sequential game with perfect and imperfect information and equal skills.



This three stage game with perfect information can be easily solved by backward induction. However, the equilibrium is dependent of assumptions about the endowment values (w) and gun cost (g). If $w>2g$ or $w<g$[10] it implies that no crime (-C) is the subgame Nash perfect equilibrium (SNPE). If $w\leq 2g$ crime without guns [(-GC), (-G)] is the SNPE. These results have some implications. In first place, the effect of gun cost on crime is not linear and ineffective. Crimes occur when the gun cost is $g<w\leq 2g$, but there is no crime outside this interval. So, a rise on gun cost only implies on a place change of the interval. Higher endowment will be necessary to crimes worth.

If imperfect information is considered at the last stage, the game equilibrium is [(GC), (G)] if $w>2g$ and [(-GC), (-G)] if $w\leq 2g$. The main difference from the game with perfect information is that non linearity effects of gun cost disappear. In this game, laws that increase gun supply reduce crimes, since a reduction in g takes the equilibrium to no crimes (when $g>w$). On the other hand, an increase in this cost until w takes the equilibrium to commit crimes without guns, after this point (g>w) not to commit crimes is again the equilibrium. Therefore, in this model, the deterrence effect is maximum under laws that expand the gun supply.

The main weakness of this model is that it assumes a violent behavior by the criminals. Even if the victim don't carry a gun a criminals will kill him without a motive. It contradicts the evidence that criminals have a small propensity to attack and to hurt their victims when they use guns when it is compared to other coercion forms (Conklin, 1972, Cook, 1976; Cook, 1980). The explanation for this behavior is that the gun gives to criminals a confrontation advantage that allow to obtain the victim's submission without the use of the force (Cook, Moore and Braga, 2002). Like victims[11], criminals use guns with self-defense purpose. In Wright and Rossi (1994), 58% of the criminals considered the self-defense

[9] This advantage is due the negative derivative of reaction curves.

[10] Note that $g > w$ is not rational even to potential victims, since the defense cost of their endowments would be greater than the endowment.

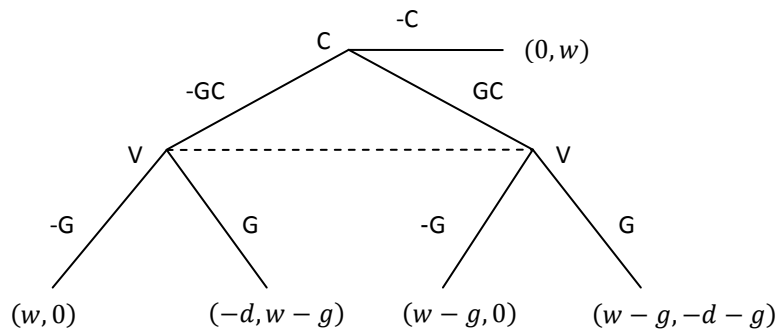
[11] Cook and Ludwig (1998) showed that 46% of gun owners buy one with intention of self-protection against criminals.

purpose the most important reason in the decision of acquiring a gun. Then, to incorporate these evidences, new assumptions are made.

The second model presented in this paper assumes that criminals are criminals and victims are victims. So, victims don't kill criminals if their lives are not threatened. Another assumption of this model is that criminals are able to choose their victims and they will choose someone who they have fight advantage. Now criminals have the surprise factor in their favor, so they don't give a chance to victims to use their guns. This assumption is based on the empirical evidence that the individuals' success rate to take out the gun after the opponent is small (McDowall, Loftin and Wiersema, 1994). For instance, Cook (1991) shows that only 3% of the victims in the sample were able to use their gun against criminals that broke in (or tried to) their residence.

Following these evidences, in this new version of the game, victims are only able to use guns when the criminal is unarmed. The payoffs of the previous game are modified to include these new assumptions. The extensive form of this modified game can be seen in the figure 2.

Figure 2 Sequential game with perfect and imperfect information and the different skills and behavior.



Considering perfect information, the unique SNPE in pure strategies of this game is [(GC), (-G)]. Differently from the previous game with perfect information, this game implies on gun crimes. But, this result also lacks of reality since victims never carry guns in the equilibrium[12]. Besides that, the gun cost doesn't affect the equilibrium, so no policy inferences could be made about it. The only value of g that changes the result is $g>w$, which is a trivial result since under this condition crimes don't worth.

When imperfect information is considered, there is no Nash equilibrium in pure strategies. Consequently it is not possible to obtain equilibrium for this two stages game. It is possible to analyze it in a static form, however, the next section studies a more complete form of this same game. An alternative analysis is only exclude the "not crime" action and consider imperfect information in the last two stages. Thereby, in mixed strategies, when attributing a probability α to criminal carry a gun and a probability β to victim to carry a gun it generates the following probability values:

$$\alpha = \frac{w-g}{w+d}, 1-\alpha = \frac{d+g}{w+d}, \beta = \frac{g}{w+d}, 1-\beta = \frac{w+d-g}{w+d} \quad (1)$$

[12] Cook et al. (2009) estimate that there are between 200 and 250 millions guns in United States. Lott (2010) states that in 1997 there were more than 5 millions of Americans with a license to carry a gun.

These results allow at least two interesting conclusions regarding the model where there is a fight advantage to criminals. In first place, in this game the best for the victim is always to choose the opposite action of the criminal, while for the criminal the best is always to choose the same victim's action. This conflict of interests takes the game to not to have equilibrium in pure strategies. In second place, the impact of an increase in the costs of gun carry is different between victims and criminals. A reduction in the cost of gun carry increase the belief of criminal's use, $\frac{\partial \alpha}{\partial g} < 0$, but, on the other hand, it reduce the belief of victims use, $\frac{\partial \beta}{\partial g} > 0$. It means that an increase in the gun supply (cost reduction) take the equilibrium where victims carry guns with smaller frequency and criminals use guns with more frequency in crimes, therefore, differently from the result obtained in the previous model, more guns implies on more gun crimes.

These results allow concluding that sequential models can be an unsatisfactory way to model crime and gun control, since they present results that don't allow inferring about gun control policy under certain circumstances and in other situations they don't have support in the empirical evidence. An alternative is to model only with games with simultaneous actions, just as the last model. The next section presents models with these characteristics, it means that static games with imperfect information are presented.

2.2.Static models with imperfect information and with mixed strategy equilibrium

Consider now that victims and criminals choose its strategies simultaneously, characterizing a game with imperfect information. Suppose that there is a possibility of lying low by the victims, being at home or preventing certain risk behaviors as to go out at night or to go to risk locations (L) with a cost $l>0$, that represents his loss of freedom. If we assume that criminals and victims have the same fight and gun skills the model is the same as the presented by Mialon and Wiseman (2005). So, these results will not be presented on this paper.

In this paper it is only presented the results of the game where criminals an absolute advantage in the confrontation. It occurs because the victim is always surprised by the criminal and because he doesn't have the same skill with guns. The victim only takes advantage in this confrontation when he has a gun and the criminal has not. In this in case, the victim felts menaced and kills the criminal with self-defense purpose, who attributes to death a cost $d>0$. The model also considers that in case of meeting of an armed criminal and an unarmed victim it generates only the loss of the endowment by the victim. In the case of a meeting between a victim armed and an armed criminal, the victim takes disadvantage in the confrontation and dies with a cost d. Thereby, the agents randomly are to play the game given for:

Table 1 Normal form of the game with equal costs.

	-G	G	L
-C	0, w	0, w-g	0, w-l
-GC	w, 0	-d, w-g	0, w-l
GC	w-g, 0	w-g, -d-g	-g, w-l

This game doesn't have ENPS in pure strategies, therefore the search is for a mixed strategies equilibrium. For this goal, a probability α_1 is denoted to commit a crime with a gun by the criminal, a probability α_2 to the criminal to commit a crime without a gun, a probability β_1 to the victim has not a gun and a probability β_2 to the victim have a gun. Four assumptions about the pay-offs are considered: $d > w > l > g$ and $2g > l$.

These assumptions implies in well behaved probabilities, however they are not so arbitrary since they can be easily justified. The first assumption implies that the biggest cost is the death cost, which is far intuitive. The endowment w is greater than the cost of carry a gun g. If the opposite is true there is no gun crime since the costs are greater than the benefits for criminals as it was commented in the last section. The endowment is greater than the cost of being at home. If the contrary is true being at home is a dominated strategy. The forth assumption means that the cost of carry a gun g should be at least a half of the cost of being at home.

Thereby, in this game, the mixed strategies equilibrium generates the following probabilities:

$$\alpha_1 = \frac{l-g}{(w+d)}, \alpha_2 = \frac{dl+wg}{w(w+d)}, (1-\alpha_1-\alpha_2) = \frac{w-l}{w}, \beta_1 = \frac{gd}{w(w+d)},$$
$$\beta_2 = \frac{g}{(w+d)}, (1-\beta_1-\beta_2) = \frac{w-g}{w} \quad (2)$$

The objective is to study how changes on costs to carry a gun, g, affects:

a) the probability of victims carry a gun, β_2;
b) the attempt to commit crimes without a gun, α_2;
c) the attempt to commit crimes with a gun, α_1;
d) the overall crimes without a gun, $\alpha_2(\beta_1)$;
e) the overall crimes with guns, $\alpha_1(\beta_1+\beta_2)$.

The players play following these probabilities in a way to be indifferent to play one or other strategies, maintaining the same expected utility. The comparative statics between g and these outcomes are:

$$\frac{\partial\alpha_1}{\partial g} = -\frac{1}{w+d} < 0; \frac{\partial\alpha_2}{\partial g} = \frac{1}{w+d} > 0; \frac{\partial\beta_1}{\partial g} = \frac{d}{w(w+d)} > 0; \frac{\partial\beta_2}{\partial g} = \frac{1}{(w+d)} > 0;$$
$$\frac{\partial\alpha_2(\beta_1)}{\partial g} = \frac{d^2l+2dwg}{w^2(w+d)^2} > 0; \frac{\partial\alpha_1(\beta_1+\beta_2)}{\partial g} = \frac{l-2g}{w(w+d)} < 0 \quad (3)$$

This model is appropriated to evaluate policies of gun control that reduce the guns supply in the legal market as well as in the illegal market, as for instance, the creation of legal barriers to buy a gun and to carry a gun, the gun taxation increase or a higher control of the

sale points and of the access to ammunition. In these cases, the gun cost increases for both players.

The results show that the gun control is able to reduce the crimes with guns, but not to reduce crimes without guns. There is a transference effect in crime. Therefore, the main conclusion is that the gun control able to reduce violent crimes, just like homicide, but it cannot be a solution to reduce the whole crime. These results don't differ from the theoretical results obtained by Mialon and Wiseman (1995) and it opposed to the empirical results from Lott and Mustard (1997). According to the authors, laws that reduce the gun costs create transference to less violent crimes, such as thefts. Though, in this model, a reduction in g increases gun crimes and it reduces the crimes without guns (less violent).

In the model, it is possible to observe another impact of the increase of guns availability: the loss of freedom. It occurs because, $\frac{\partial(1-\beta_1-\beta_2)}{\partial g} < 0$, consequently, there is a loss of welfare to potentials victims that go out to street with less frequently in a context with more guns. It is a theme not so discussed in the literature, but it can generate relevant distortions in empirical works[13].

It should be noted that the model presents two different sources of costs to criminals. One is imposed by the legal system and it is represented by g, the other is imposed by the victim that can react and then to impose a cost d for the criminal. But, which cost has the largest deterrence power in gun crimes (more violent)?

Proposition 1. *If* $\beta_1 > \alpha_1$, *so,* $\frac{\partial\alpha_1(\beta_1+\beta_2)}{\partial g} < \frac{\partial\alpha_1(\beta_1+\beta_2)}{\partial d}$.

Proof: appendix.

The proposition 1 implies that the punishment imposed by the legal system can be less efficient (inferior marginal impact) than the punishment out of legal system if the victim's probabilities of gun carry is superior to criminal's probability to commit gun crimes. It corroborates with the argument that the reaction possibility have a deterrence power that cannot be ignored in theoretical crime models. Wright and Rossi (1994) showed that 74% of the criminals would avoid entering in residences when their residents are present due to the fear of being reached by a shot and that 40% of the same ones gave up on practicing a crime because they feared that the potential victim was carrying a gun.

An interesting extension of this game is to consider that victims and criminals have different costs of carrying a gun by alterations in the guns demand. Chaudhri and Geanakoplos (1998) argue that the demand for guns would be elastic and, consequently, turn gun carry illegal would generate a supply change that would be able to reduce the amount of guns. Bartley (1999) argues that turn the guns illegal would only harm those that intend use it legitimately and that an alternative policy would be to change the demand. Changes in the demand occur, for instance, when a new policy alters the legislation introducing more severe punishments for crimes practiced with gun use (Cook and Ludwig, 2006).

In this context, the criminals have an additional cost given by $b=pf>0$. Where p is the punishment probability to a gun crime and f is the punishment severity. Thereby, the game with imperfect information will be:

[13] The omission of a relevant variable correlated with the remain regressors (guns quantity) generates inconsistent estimators.

Table 2 Normal form of the game with different costs.

	-G	G	L
-C	0, w	0, w-g	0, w-l
-GC	w, 0	-d, w-g	0, w-l
GC	w-g-b, 0	w-g-b, -d-g	-g-b, w-l

Considering the same assumptions about the pay-offs of the first model and that $w>g+b$, the unique mixed strategy equilibrium has[14]:

$$\beta_1^* = \frac{gd}{(w-b)(w+d)}, \beta_2^* = \frac{wg}{(w-b)(w+d)}, (1-\beta_1-\beta_2)^* = \frac{w-g-b}{w-b} \quad (4)$$

Comparing these probabilities with the preview model, it can be observed that the probability of not lying low is greater, so, in this model, victims go out more. It means that a greater cost to gun carry by criminals creates a security sensation for victims. The marginal effects of an increase in the costs to carry a gun for criminals are:

$$\frac{\partial\alpha_1}{\partial b} = \frac{\partial\alpha_2}{\partial b} = 0; \frac{\partial\beta_1^*}{\partial b} = \frac{dg}{(w-b)^2(w+d)} > 0; \frac{\partial\beta_2^*}{\partial b} = \frac{wg}{(w-b)^2(w+d)} > 0;$$
$$\frac{\partial\alpha_2(\beta_1^*)}{\partial b} = \frac{dg(dl+wg)}{w(w-b)^2(w+d)^2} > 0; \frac{\partial\alpha_1(\beta_1^*+\beta_2^*)}{\partial b} = \frac{g(l-g)}{(w-b)^2(w+d)} > 0 \quad (5)$$

An increase in the costs to carry a gun by criminals does not affect the choice of the criminals between committing crimes without guns or with guns. Thus, the victims increase their freedom leaving home more and increase their gun use in the accurate measure to leave the criminals indifferent again.

The most important result of this game is that the effect in crimes without guns and with guns is positive. It allows concluding that an increase in the costs of carrying a gun by criminals increases the probabilities to occur crimes, with guns and without guns. This happen because it increases the security sensation by victims, who changes their behavior leaving home more frequently, and therefore, they became more susceptible to be a crime victim with or without guns. So, laws that introduce harder punishment to gun crimes may have a different effect from the expected by their proposers. This result supported by the empirical evidence obtained by Raphael and Ludwig (2003) that studied the Project Exiles applied in Richmond and concluded that the punishments increase to gun crimes didn't reduce the gun crimes.

2.3. Dynamic model with incomplete information (signaling game)

An important extension is to model crime and gun control under asymmetric information. In this model, it is assumed that victims have information advantage over criminals. It means that when criminals choose their victims, they are not able to identify

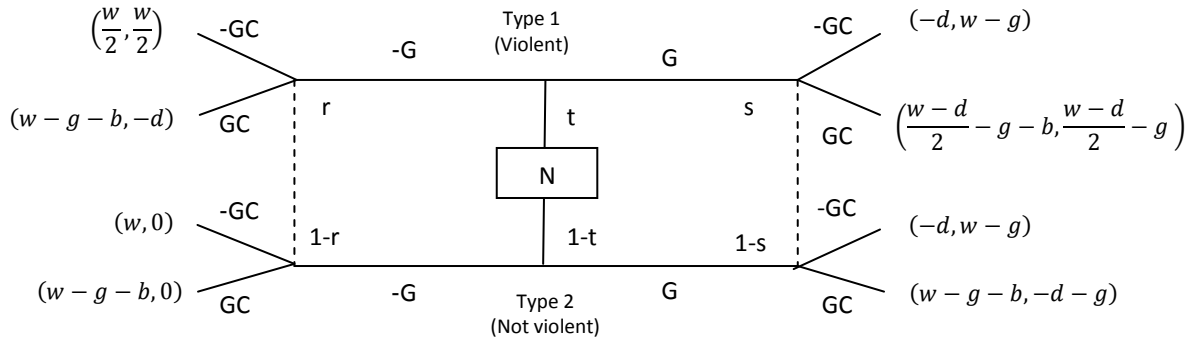
[14] Note that α's does not change and that the symbol (*) was added to represent the modified probabilities.

their reaction capacity. This idea follows the essence of positive externality created by the guns, since criminals, in general, are not able to distinguish the individuals that carry guns (Kleck, 1988; Lott, 2010), so, they are not able to evaluate the victims' reaction capacity. It is an important deterrence effect which is omitted in the previous theoretical works.

Following this reasoning, the model of this section establishes that Nature determines victim's type with probability $t \in T$. Victims can be violent (type 1) or not violent (type 2). The type 1 victim has the same skills as criminals have, so the payoffs are the same as Mialon and Wiseman (2005), we call it a violent victim. The type 2 has fewer skills fighting and shooting with a gun and never kills the criminal, we call it a not violent victim. In the model, for simplicity, the victims' action of lying low is excluded.

The main advantage of this model is that this allows considering the victims' possibility not to always kill the criminals. Victims of the type 2 don't kill the criminals when these don't carry guns. It means to say that in this game, victims of the type 2 are really victims. Anyway, the victim of the type 1, only kill the criminal in the case of his life is threatened. It happens when the criminal announces the assault not carrying a gun. However, criminals are not threatened by victims of the type 2 and, therefore, they don't kill them when these don't carry guns. The criminals commit murders when they notice that the victim is of the type 1[15]. Thereby, victims and criminals kill their opponents when they feel that their lives are under risk and when they have conditions to do it[16]. Thus, the payoffs are the same as previous section including the different costs of gun carrying to victims and criminals. The extensive form of this game is shown in the figure 3.

Figure 3 Dynamic game with incomplete information.



The equilibrium of this signaling game is obtained through a Bayesian Nash Perfect Equilibrium (BPNE)[17]. The four possible pure strategy Bayesian equilibrium in this two-type and two-message game are: (a) pooling on -G, (b) pooling on G, (c) separating with type 1 playing G and type 2 playing -G and (d) separating with type 1 playing -G and type 2 playing G. These possibilities are analyzed in turn considering any prior belief regarding the victim type by criminal.

[15] Wright and Rossi (1994) showed that 40% of the criminals wound the victims because they believe that the victims were carrying a gun.

[16] Kill an opponent certainly is not simple. It evolves costs, such time explaining to Police and psychological costs.

[17] In this case, the equilibrium is the same as obtained by sequential equilibrium of Kreps and Wilson (1982).

a) Pooling on -G

In this case, the criminal reacts to the institutional outline and their beliefs are depend of the gun costs and of the punishment for gun crimes, he plays - GC if $r < 2(g+b)/w$, so the victim of the type 1 receives $w/2$ and the victim of the type 2 receives 0, otherwise, if $r > 2(g+b)/w$, the criminal plays GC and the victim of the type 1 receives - d and the victim of the type 2 receives 0.

Considering the first belief by the criminal, there is a pooling equilibrium in - G if the criminal's answer to G is GC. It always happens, because any positive probability of being alive is better than to die with probability equal to one. Even when it is considered the case where the victim of the type 2 doesn't kill the criminal when he is unarmed it is an equilibrium, since, in this case, G will be the best answer to GC if[18] $s > 2(g+b-w)/(d-w)$.

Considering the second belief there is no pooling equilibrium in -G. Therefore, with low costs and less severe punishment for gun crimes doesn't exist the equilibrium where both types of victims choose to carry guns. It may happen when the costs are high and/or when the punishment is more severe[19], besides, the answer to G should necessarily be GC, and in other words, the victims should believe that if they carry guns necessarily the criminals will also carry. Thereby, it is obtained a pooling equilibrium {(- G,-G),(-GC,-GC), r, s} for any s and $r < 2(g+b)/w$.

b) Pooling on G

In this case the criminal chooses GC independent of his belief regarding the type of the victim. Consequently, the victim of the type 1 receives $(w-d)/2-g$ and the victim of the type 2 receive $-d-g$. In this game there is no pooling equilibrium on G because the victim of type 2 always has incentive to deviate from the confrontation, so, he chooses - G.

c) Separating with type 1 playing G and type 2 playing -G

If the type 1 signalize with G the best to the criminal is to choose GC, in this case the victim receives $(w-d)/2-g$, it is better than the deviation alternative. The signaling of the type 2 implicates in the choice of - GC by criminals, so the victims answer with G, it is an empty threat, because the criminals will answer to this threat with GC and the victim, in this case, chooses -G. Therefore, {(G,-G), (GC,GC), s=1, r=0} is a equilibrium. Notice that in this equilibrium the criminals always carry guns independently of the victim's type, of the costs and of the punishment.

[18] Note that the numerator is negative while the denominator is positive if the established assumptions about the payoffs are followed.

[19] Should be emphasized that more severe punishment means an increase in b, which can occur with an increase in f as much as an increase in p.

d) Separating with type 1 playing -G and type 2 playing G

If the type 1 plays –G the equilibrium in pure strategies only exists if the condition $w/2>w-g$ is satisfied. In other words, it is necessary that the costs are high enough so that criminal and victim of the type 1 choose to not carry guns. In response to G by the type 2 the criminal chooses GC, the victim in this case chooses -G, so the criminal answers with -GC, in this case, the best answer for the victim of the type 2 is to play G if the expected value of playing G is larger than zero (payoff of playing -G). Let q be the criminal's probability to play -GC against the victim of the type 2, he plays G if the condition $q>(d+g)/(w+d)$ is satisfied. Therefore, the equilibrium {(- G,G), (-GC,GC), s=0, r=1} is a BPNE that satisfies the two previous conditions, in other words, if $w>g+b>w/2$. Thereby, this separating equilibrium only occurs when the gun costs are high.

The efficiency of the signaling is conditioned to the traditional rationality restrictions and incentive compatibility, in other words, the first establishes that the victim of the type 1 is in fact in a better situation in a separating equilibrium than in a pooling equilibrium and the second establishes that the victim of the type 2 doesn't have incentive to carrying a gun.

In this game the signaling is efficient if there are low gun costs[20], because it eliminates the pooling equilibrium and the separating equilibrium where the type 2 carry a gun, but the type 1 doesn't carry a gun. Under this condition, the signaling is efficient and guns are acquired by "good hands", because only individuals with skills and with some chance in a confrontation carry guns. It allows concluding that policies like "shall issue laws" guarantee the uniqueness of the equilibrium and they are capable to disarm a part of the population, however, they are not capable to disarm the criminals, since them always carry guns in this unique equilibrium.

This result implicates that criminals will always carry guns even when they have advantage in the confrontation. It is important to point out that this result appears in the model without any different assumption regarding the behavior toward the risk[21]. The crime is a risk activity and is not possible to distinguish the victims' behavior in certain circumstances. Besides, the result doesn't eliminate gun crimes and the confrontation with victims of the type I generates deaths to both victims of this type and criminals. It follows the idea of Cook and Ludwig (2006), that state, p. 33, "*if increased gun carrying among potential victims cause criminals to carry guns often themselves, or became quicker to lives uses guns to avert armed self-defense, the end result could be that street crime more lethal*".

However, the signaling is not efficient when the costs of gun carry are high and the punishment for gun crimes is severe. This policy originates a pooling equilibrium which victims don't carry guns and gun crimes don't occur. This result is the best in the Pareto sense and achieve the main objective of a disarmament policy, it reduce deaths. Should be emphasized that this equilibrium can be obtained with an increase in the costs of obtaining a gun (g), with the increase of the punishment (f) and with an increase of the probability of being punished by a gun crime (p). Obviously those policies involve different costs and it is the role of a policymaker to evaluate the effectiveness of them in the reduction of guns carried by victims and criminals.

Nevertheless, it is not the only equilibrium under these conditions (high costs), there is another separating equilibrium which the type 1 doesn't carry a gun, but the type 2 carry a

[20] Note that the separated equilibrium which type 1 carry a gun and type 2 does not carry a gun is independent of costs and punishment, so, low cost only guarantee equilibrium uniqueness.
[21] In all models criminals are assumed to be risk neutral.

gun[22]. This is the victim type that doesn't have fight ability and, for this reason, carry a gun to equilibrate the confrontation against the criminals. In this equilibrium, the victims that die are those that don't have skills handling guns. This result raises the discussion regarding the victims' profile that will carry guns after policies that reduce the availability of guns are in practice. Cook et al. (2002) argue that guns may go the more violent individuals' hands, since they would have an inelastic demand. However, the model shows that an increase in the costs put guns in the individuals' hands that have disadvantage in the confrontation. The criminals in this equilibrium, alternate among crimes without guns and gun crimes. This result reproduces the empirical evidence that guns are not used in all crimes. Cook and Ludwig (2006) show that in 2002, about 42.1% of the robberies involved guns.

Maybe the most important conclusion of this model is that none policy regarding guns is able to finish deaths, since individuals which believe to have chances in confrontations will always carry guns independent of their costs and, therefore, always will occur confrontations with deaths. Although through this model it is not possible to infer quantitative changes in crime, it is possible to infer that gun policy just determine which type will be the victims that will die. Under policies that facilitate the access to guns the victims of the type I will die, under restrictive policy with less severe punishment, the victims of the type II will die. More severe punishment for gun crimes is able to save the victims of the type II. It is difficult to determine a priori in this model which policy is able to save more lives because it depends on the share of each type in the population.

3. Conclusions

This paper presented some important modifications regarding the previous theoretical works that evaluate gun policy with the economy of the crime approach. The main modifications are the inclusion of the first mover advantage to criminals, the different gun costs for victims and criminals and different forms of information that are considered. These assumptions turned the games more realistic and more adequate to analyze, for instance, situations of street robberies, the most common economic gun crime. However, should be point out that this paper doesn't allow evaluating the impact of guns availability for other objectives, such as the use against other individuals without economic motivation or suicides. These are relevant social problems, but that cannot be analyzed using this methodology. Certainly, it is an important paper limitation.

The different assumptions about information generated interesting results. Under imperfect information, the results show that the gun control is not able to reduce crimes without guns and, therefore, the transfer effects don't allow that the whole criminality decreases. Besides, the models showed that gun control policy is more efficient when they affect the costs to both criminals and victims. The model with incomplete information allows concluding that a better equilibrium exists in the Pareto sense that can be achieved with gun costs increase, though, it doesn't guarantee an unique equilibrium. The equilibrium uniqueness only occurs in a context with low cost and less severe punishment for gun crimes. In this equilibrium, the signaling works, but, criminals always carry guns. Thereby, criminals

[22] Higher punishment to gun crimes can eliminate this equilibrium, however, the model maintain multiple equilibrium.

carry guns even they have advantage in confrontations, since crime is a risk activity and gun is like insurance on the criminal activity.

This paper also analyzed the effects of the guns availability through a crime and self-defense model and it concluded that more guns implies on more crimes when is assumed that criminals have some advantage in confrontations. This result implicates that, under these conditions, the availability effect dominates the deterrence effect.

Thus, laws that facilitate the access the guns, such as "shall issue laws" and 'may issue laws" may have different effects from the expected by their proposers. Then, the advisable policy for gun crime reduction are policies that increase the costs of gun carry for both criminals and victims, once that the model presented in the section 2.2 show that gun control is more efficient when it affect the victims and criminal' costs, it means that policies like harder punishment for gun crimes are not efficient to reduce the criminality. It is the only way to obtaining an equilibrium with less gun crimes, and, for consequence, deaths. Yet, it should be emphasized that this cost cannot be so high because it would sterilize the positive externalities of the gun carry by victims and it would generate loss of freedom (welfare) to victims.

Finally, it should be pointed out that the crime reduction involves more factors than gun control. Several works since Becker (1968) have been showing that the cost of the criminal action is more than simply the gun carry cost, since guns are just an production input (supply) of crimes and a component of the demand for crimes. Though, other cost sources may exist, for instance, the opportunity costs, stigma and moral costs of committing a crime. For instance, policies that increase the demand for workers in the legal sector would increase the opportunity costs. These policies can be more effective than gun control to achieve the reduction of crime.

4. References

AYRES, I., DONOHUE III, J.J. "Shooting down the more guns, less crime hypothesis". *Stanford Law Review*, 55, 1193–1312, 2003.

BARTLEY, W.A. "Will rationing guns reduce crime?". *Economics Letters*, 62, 241-243, 1999.

BECKER, G.S. "Crime and punishment: an economic approach". *Journal of Political Economy*, 76, 169–217, 1968.

BLACK, D.A., NAGIN, D.S. "Do right-to-carry laws deter violent crime?" *Journal of Legal Studies*, 27, 209–219, 1998.

BLOCK, M. K., GERETY, V.E. "Some experimental evidence on differences between student and prisoner reactions to monetary penalties and risk". *Journal of Legal Studies*, 24, 123-138, 1995.

CHAUDHRIA, V. GEANAKOPLOS, J. "A note on the economic rationalization of gun control". *Economics Letters*, 58, 51–53, 1998.

CONKLIN, J. E. *Robbery and the Criminal Justice System*. Philadelphia: Lippincott, 1972.

COOK, P. J. "A strategic choice analysis of robbery". In: Skogan, W. (ed). *Sample Surveys of the Victims of Crimes*, 173-187. Ballinger, 1976.

____. “Reducing injury and death rates in robbery.” *Policy Analysis*, 1, 21-45, 1980.

____. “The effect of gun availability on violent crime patterns”. *Annals of the American Academy of Political and Social Science*, 455, 63-79, 1981.

____. “The technology of personal violence”. In: *Crime and Justice: A Review of Research*, Tonry, M. (ed), 1-70, Chicago: University of Chicago Press, 1991.

COOK, P.J., LUDWIG, J. “Defensive gun uses: new evidence from a national survey”. *Journal of Quantitative Criminology*, 14 (2), 111-131, 1998.

____. “The social costs of gun ownership”. *Journal of Public Economics*, 90, 379-391, 1996.

____. “Aiming for evidence-based gun policy”. *Journal of Policy Analysis and Management*, 25 (3), 691-735, 2007.

COOK, P. J.; MOORE, M. H.; BRAGA, A. A. “Gun control”. In: . J.Q. Wilson; J. Petersilia (eds.). *Crime and Public Policy*, 257-293, Oxford: Oxford University Press2002.

COOK, P.J.; LUDWIG, J.; SAMAHA, A.M. “Gun control after *Heller*: threats and sideshows from a social welfare perspective”. Mimeo, 2009.

DEZHBAKHSH, H., RUBIN, P.H. “ The effect of concealed handgun laws on crime: beyond the dummy variables”. *International Review of Law and Economics*, 23, 199–216, 2003.

DUGGAN, M. “More gun, more crime”. *Journal of Political Economy*, 109, 1086–1114, 2001.

HEMENWAY, D. “Survey research and self-defense gun use: an explanation of extreme overestimates”. *The Journal of Criminal Law and Criminology*, 87(4), 1430-1445, 1997.

KATES, D. B.; POLSBY, D. D. “The myth of the “Virgin Killer”: Law-abiding persons who kill in a fit of rage”. Mimeo, 2000.

KELLERMANN, A.L, RIVARA, F.P., RUSHFORTH, N.B. “Gun ownership as a risk factor for homicide in the home”. *New England Journal of Medicine*, 329, 1084-1091, 1993.

KLECK, G. “Crime control through the private use of armed force.” *Social Problems*, 35, 1-21, 1988.

KLECK, G., GERTZ, M. “Armed resistance to crime: The prevalence and nature of self-defense with a gun”. *Journal of Criminal Law and Criminology*, 86, 150-187, 1995.

KLECK, G; PATTERSON, E. B. “The impact of gun control and gun- ownership levels on violence rates”. *Journal of Quantitative Criminology*, 9, 249-287, 1993.

KOVANDZIC, T.; SCHAFFER, M.E.; KLECK, G. “Gun prevalence, homicide rates and causality: a GMM approach to endogeneity bias”. *CEPR Discussion Paper*, DP5357, 2005.

____. “Estimating the Causal Effect of Gun Prevalence on Homicide Rates: A Local Average Treatment Effect Approach**”.** *IZA Discussion Paper*, WP3589, 2008.

KREPS, D.; WILSON, R. “Sequential equilibria”. *Econometrica*, 50(4), 863-894, 1982.

LOTT, J. R. “The Concealed Handgun Debate”. *Journal of Legal Studies*, 26 (1), 221-243, 1998.

____. *More Guns, Less Crime*. 3rd edition. Chicago: University of Chicago Press, 2010.

LOTT, J.R., MUSTARD, D.B. “Crime, deterrence, and right-to-carry concealed handguns”. *Journal of Legal Studies*, 26, 1–68, 1997.

LUDWIG, J. “Concealed gun-carrying laws and violent crime: evidence from state panel data”. *International Review of Law and Economics*, 18, 239–254, 1998.

____. “Gun self defense and deterrence”. *Crime and Justice*, 27, 363-417, 2000.

MCDOWALL, D; LOFTIN, C.; WIERSEMA, B. “The incidence of civilian defensive firearm use”. *American Journal of Public Health*, 84, 1982-1985, 1994.

____.“Easing concealed- firearm laws: effects on homicide in three states”. *Journal of Criminal Law and Criminology*, 86(1), 193-206, 1995.

MIALON, H.M., WISEMAN, T. “The impact of gun laws: A model of crime and self-defense”. *Economics Letters*, 88,170–175, 2005.

MOORHOUSE, J. M., WANNER, B. “Does gun control reduce crime or does crime increase gun control?”. *Cato Journal*, 26(1), 103-124, 2006.

NIELSON, W. S., WINTER, H. “On criminals’ risk attitudes”. *Economic Letters*, 55, 97-102, 1997.

RAPHAEL, S.; LUDWIG, J. “Prison sentence enhancements: The case of Project Exile”. In: Ludwig, J., Cook, P.J. (Eds.), *Evaluating Gun Policy*. Washington: Brookings Institution Press, 251-287, 2003.

SKOGAN, W. “Guns Use in Robbery: Patterns and Policy Implications.” Center for Urban Affairs, Northwestern University. Unpublished, 1978.

TAYLOR, R. “A game theoretic model of gun control”. *International Review of Law and Economics*, 15, 269-288, 1995.

VERNICK, J.S.; HEPBURN, L.M. “State and federal gun laws: Trends for 1970-1999.”.In: Ludwig, J.; Cook, P. (eds.). *Evaluating Gun Policy*: Effects on crime and violence. Washington: Brookings Institution Press, 2003.

WOLFGANG, M. E. “A tribute to a view I have opposed.” *Journal of Criminal Law and Criminology*, 86(1), 188-92, 1995.

WRIGHT, J.D., ROSSI, P.H. *Armed and considered dangerous*: A survey of felons and their firearms (Expanded Edition). New York: Aldine Press, 1994.

ZIMRING, F. E. “Is gun control likely to reduce violent killings?”. *University of Chicago Law Review*, 35, 21-37, 1968.

5. Appendix

Proof of proposition 1:

$$\frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial g} = \alpha_1\left[\frac{\partial \beta_1}{\partial g} + \frac{\partial \beta_2}{\partial g}\right] + \frac{\partial \alpha_1}{\partial g}[\beta_1 + \beta_2] = \frac{l-2g}{w(w+d)} \quad \text{(A1)}$$

$$\frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial d} = \alpha_1\left[\frac{\partial \beta_1}{\partial d} + \frac{\partial \beta_2}{\partial d}\right] + \frac{\partial \alpha_1}{\partial d}[\beta_1 + \beta_2] = \frac{-g(l-g)}{w(w+d)^2} \quad \text{(A2)}$$

But, note that:

$$\alpha_1\left[\frac{\partial \beta_1}{\partial g} + \frac{\partial \beta_2}{\partial g}\right] = \frac{\alpha_{1-\beta_1}}{w} \quad \text{(A3)}$$

$$\frac{\partial \beta_1}{\partial d} + \frac{\partial \beta_2}{\partial d} = 0 \quad \text{(A4)}$$

Substituting A3 and A4 in A1 and A2, respectively, we have:

$$\frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial g} = \frac{\alpha_{1-\beta_1}}{w} < \frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial d} = -\frac{\alpha_1 g}{w(w+d)} \quad \text{(A5)}$$

Thus, the gun costs will be smaller than victims reaction costs if:

$$g < \left(\frac{\beta_1-\alpha_1}{\beta_1}\right)(w+d). \quad \text{(A6)}$$

So, $\beta_1 > \alpha_1$ implies on $\frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial g} < \frac{\partial \alpha_1(\beta_1+\beta_2)}{\partial d}$, since $d > w > g$.