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**Peaceable Kingdoms and War Zones:  
Pre-emption, Ballistics and Murder in Newark**

*Brendan O'Flaherty*  
*Rajiv Sethi*

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*Department of Economics*  
*Columbia University*  
*New York, NY 10027*

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# Peaceable Kingdoms and War Zones: Preemption, Ballistics and Murder in Newark\*

Brendan O’Flaherty<sup>†</sup>

Rajiv Sethi<sup>‡</sup>

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## Abstract

Between 2000 and 2006 the murder rate in Newark doubled while the national rate remained essentially constant. Newark now has eight times as many murders per capita than the nation as a whole. Furthermore, the increase in murders came about through an increase in *lethality*: total gun discharges rose much more slowly than the likelihood of death per shooting. In order to explain these trends we develop a theoretical model of murder in which preemptive killing and weapon choice play a central role. Strategic complementarity amplifies changes in fundamentals, so areas with high murder rates (war zones) respond much more strongly to changes in fundamentals than those with low murder rates (peaceable kingdoms). In Newark, the changes in fundamentals that set off the spiral were a collapsing arrest rate (and probably a falling conviction rate), a reduction in prisoners, and a shrinking police force.

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<sup>†</sup>Department of Economics, Columbia University (bo2@columbia.edu).

<sup>‡</sup>Department of Economics, Barnard College, Columbia University (rs328@columbia.edu).

“If I had not put an end to him today, he would have killed me tomorrow.”<sup>1</sup>

## 1 Introduction

In 2006, 105 people were murdered in Newark, New Jersey, almost twice as many as were murdered in 2000. If murders occurred in Newark at the national rate, there would have been 13. Using standard measures of the value of a statistical life, this implies a loss of \$460-\$644 million from excess murders in Newark in 2006.<sup>2</sup> The entire cost of running city government was firmly in that range. Furthermore, while the increase in murder can be attributed almost entirely to an increase in gunshot homicides, the overall incidence of shooting incidents did not rise appreciably. What happened was a dramatic increase in *lethality*: far more shootings now result in victim death. Why are so many people killed in Newark? Why did murders rise so sharply from 2000 to 2006? Why did the increase come about through greater lethality rather than more frequent shooting? What can be done to reduce the killing? And more generally, what changes in fundamentals trigger changes in lethality and the incidence of murder, and how does the mechanism operate? These are questions that we address in this paper.

Murder differs from other serious crimes in several important respects. To begin with, murder is defined in part by a medical condition—clinical death—and random chance plays a major role in determining whether most attempts at killing end up becoming murders. Second, murder admits a much wider array of motives than most other crimes, including jealousy, rage, paranoia, vengeance and greed. Third, even in the absence of any legal sanction for murder, ordinary people under normal circumstances would gain little from taking the life of another. This is clearly not the case for crimes such as robbery or theft.

Fourth, murder is extremely serious. Most individuals value life more than they value large amounts of money, and are willing to pay substantial sums to avoid even small increases in the risk of death. The average murder results in welfare losses estimated to be at least 5000 times as large

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<sup>1</sup>Grace Doyle of Chicago, July 3, 1899, explaining why she shot her husband Timothy (quoted in Adler, 2006, p. 101).

<sup>2</sup>Aldy and Viscusi (2003) is a definitive reference on this topic. Levitt and Venkatesh (2000) estimate that young gang members in Chicago act as if they value their lives at much lower rates—an order of magnitude or two lower. Since these estimates are so far below the norm in this huge literature, perhaps some of the standard assumptions do not hold—the decision-makers may not be aware of true probabilities, for instance, or their outside opportunities may not be accurately modeled. Many Newark murder victims resemble the young gang members studied by Levitt and Venkatesh, but many do not.

as the losses from the average robbery (Aldy and Viscusi, 2003). Hence people are willing to take drastic steps to avoid being killed, and these steps may include *the preemptive killing of others*. Our simplest answer then to the question of why people kill so often in Newark is that they kill to avoid being killed. Other motives are present, to be sure, but huge deviations from national norms can be sustained only if a significant proportion of murders are motivated by self-protection. Some Newark streets are sometimes described as a war zone, and in war too, soldiers kill to save their lives and those of their comrades.

More precisely, the decision to kill is characterized by strategic complementarity: an increase in the likelihood of being killed by someone raises the incentives to kill them first.<sup>3</sup> Under such circumstances it is possible for expectations of high murder rates to become self-fulfilling: murders beget murders. Furthermore, small changes in fundamentals can, under certain circumstances, induce large changes in the equilibrium murder rate. We show how this can happen as a result of a dramatic change in the choice of lethality, so that murders increase even as shootings remain relatively stable. We believe that this is what happened in Newark in the early years of this century. While we cannot identify any single trigger, several changes occurred that may have been enough to shift the equilibrium drastically: the prosecutor's office fell into disarray, the number of prisoners decreased, the police department withered, and the corrections department reorganized state prisons in a way that facilitated networking among gang members. Taken together, the impact of these changes was to drive expectations beyond a tipping point, resulting in a cascade of killings motivated in part by self-protection.

Our model is useful prospectively as well. How can Newark's murders be cut? The obvious answer is to improve fundamentals—for instance, by investing in high quality professional police work that increases the probability that murderers will be apprehended and convicted. Once a high murder regime has been entered, however, it cannot be escaped simply by restoring fundamentals to their initial values. According to our analysis, the corrective changes that are required in order shift expectations of murder rates back down to earlier levels may be much greater in magnitude than the changes that triggered the rise in the first place. The analysis also tells us what sorts of public relations efforts to mount and which to avoid. More speculatively we look at ideas like multiple classes of liquor licenses and other efforts to quarantine the contagion of violence.

The idea that two armed individuals may choose to shoot at each other simply out of fear that

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<sup>3</sup>Thus our story is an example of the social multiplier discussed in Goldin and Katz (2002) and Glaeser et al. (2003).

they may be shot first dates back at least to Schelling (1960). Even when both parties to a potential conflict prefer that no violence occurs, uncertainty about the motives or intentions of others can result in mutual aggression. This process has been modelled formally as a coordination game with incomplete information by Baliga and Sjöström (2004), who identify conditions under which there is a unique (Bayes-Nash) equilibrium in which both players attack with certainty.<sup>4</sup> We build on this work by introducing the possibility that individuals face not just the option of violence but also a choice of lethality, where greater lethality must be purchased at some cost. This allows us to explore how equilibrium levels of lethality and murder co-vary with the underlying parameters of interest. For instance, one implication of our model is that a deterioration in fundamentals causes murders to rise more rapidly than shootings, so the ratio of shootings to murders declines.<sup>5</sup> This is fully consistent with the Newark data.

The plan of the paper is the following. We begin by describing the time trend of murders in Newark and in the nation as a whole. Newark's time trend is unusual (though not unique) within the nation, but not unusual within New Jersey. This tells us that we cannot simply appeal to national trends to explain what is happening—nor do Newark officials have to wait for national trends to right themselves. Section 3 is about the mechanics of murder in Newark. Demographically, the rise is confined almost exclusively to African-American men, but not confined by time or premises. Gunshot wounds are entirely responsible for the rise, but not because there were more shootings. The primary story is that shootings became more lethal, and they did so on many dimensions—more multiple shot incidents, more high-caliber weapons, and more just plain accuracy. Section 4 presents our model and shows some of the correspondence with Newark data. Section 5 reviews some of the existing empirical literature in economics on murder, and shows how our model is consistent with this literature. We concentrate on arrest rates, incarceration, and police strength. At first glance, murder appears nowhere near so responsive to fundamentals as our model indicates it should be in many cities, but we show several reasons why many of the papers we review would

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<sup>4</sup>This happens because there is some proportion, possibly very small, of individuals for whom aggression is a dominant strategy. The presence of such types places a lower bound on the likelihood of being attacked, which induces some individuals for whom aggression is *not* a dominant strategy to also attack. Applying this reasoning iteratively one can see that peace may be impossible to support in equilibrium provided the the distribution of the costs of aggression does not rise too steeply. Baliga and Sjöström explore the possibility that cheap talk could allow the parties to coordinate on the peaceful outcome. Basu (2006) applies a variant of this model to examine racial conflict, and Baliga et al. (2007) extend it to study the manner in which political institutions affect the likelihood of war.

<sup>5</sup>In fact, we show that it is theoretically possible for shootings to decline in absolute terms even as murders rise.

miss the responsiveness in situations like Newark's.

Next, in section 6, we look at the possible changes in fundamentals that could have driven the increase we observe. Upper bound estimates on the three fundamentals account for a large part of the rise in murder in Newark, and we think that strategic complementarity can explain much of the rest. We review witness intimidation, and show how it complements the answers we are proposing. We also show why many New Jersey cities experienced the same rise in murder that Newark did at about the same time. On the other hand, we argue that interjurisdictional spillovers and changes in the drug and gun markets and in the macroeconomy explain little of the trend in Newark. Finally, in section 7, we turn to policy. We look at the three most famous incidents of murder reduction (Boston, Richmond, and New York City), critically review the literature on whether the associated programs actually caused the reductions, and draw implications for the city of Newark. The second half of section 7 presents our tentative recommendations for Newark, and section 8 concludes.

## 2 Murder trends

Figure 1 compares the murder rate in Newark since 1977 with the national rate. To make the two series comparable, we set their 2000 values equal to 100. Both series peak in the 1980, and fall until around 2000. (Newark's trough is actually 1997, but the number of murders in 1997 is only two different from the number in 2000.) The fall in Newark murders is more precipitous than the fall in national murders, and does not seem to be interrupted by the crack epidemic, unlike the national series. As expected, murders in Newark fluctuate more than the aggregate for the nation as a whole, although the two series track each other quite closely until 2000. After that, the picture changes. The national series stays essentially flat (preliminary data indicate no change in the first half of 2006 compared with the first half of 2005), but Newark rises. By 2005, which is approximately the same as 2006, Newark murders have returned to their late-1980s, early-1990s level: below the peak, but substantially above the trough. Newark has also sustained this level for several years.

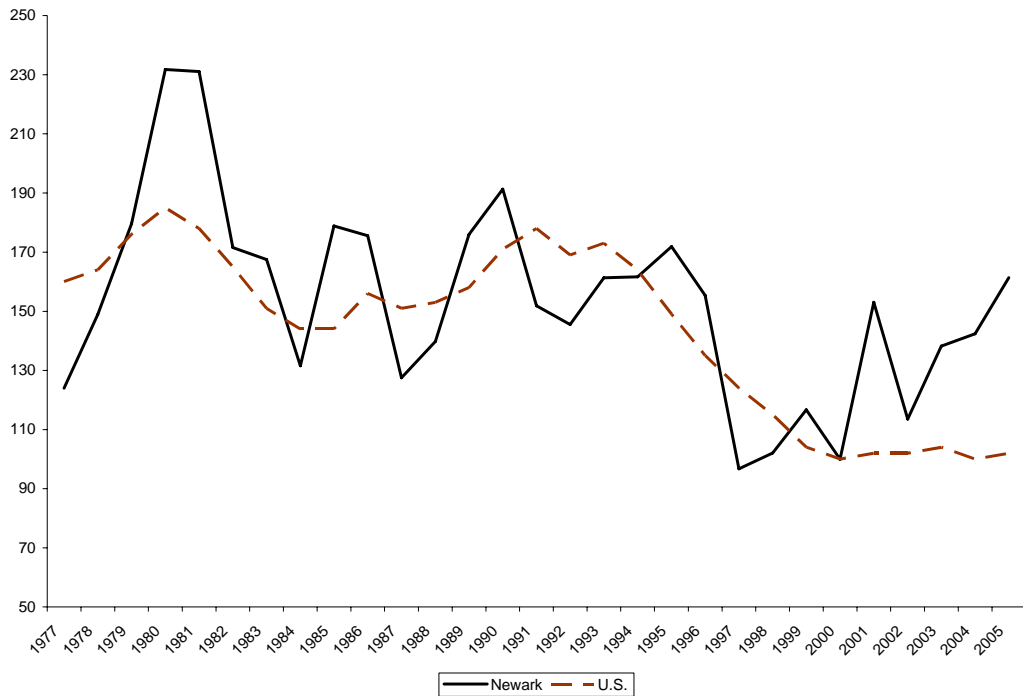


Figure 1. Newark and U.S. Murder Rates, 1977-2005

The increase in murders that Newark experienced is not a national phenomenon or even a national urban phenomenon. Among large cities, only Boston and possibly Houston are like Newark. Figure 2 shows the percentage change in murders for the ten largest cities, and all other cities with at least as many African-American residents (146,000) as Newark had in 2000. We omit New Orleans because of the incomparable events that occurred there (although superficially it appears that homicide in New Orleans is well described by our model). The comparison is between the geometric mean of 1998 and 1999 murders, and the geometric mean of 2004 and 2005 murders.<sup>6</sup> Clearly there was no general increase in murder in big cities during this period. Ten of the 21 cities other than Newark experienced decreases, and only Boston, which started at a very low level, saw a bigger increase. Most of the cities in this table had bigger population increases than Newark did. Hence one cannot appeal to national phenomena, or even to national urban phenomena, to explain what has been happening in Newark.

<sup>6</sup>We use two years to smooth out some noise, and we use the geometric mean because we are interested in percentage changes. The 1999 data is not available for Baltimore, so in this case we use just 1998 (Source: FBI, Uniform Crime Reports).

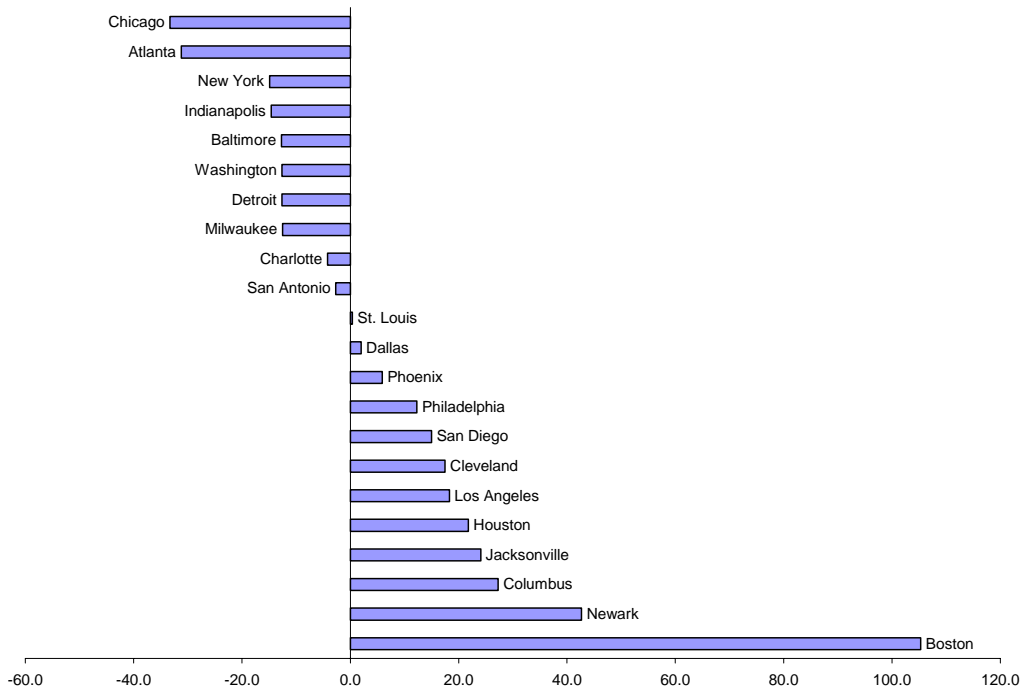


Figure 2. Percentage Change in Murders, 1998-99 to 2004-05, Large Cities

Recently the Police Executive Research Forum (2007) has released a report pointing to a surge in violent crime in cities in 2005 and 2006. The report does little to change the conclusion that Newark is exceptional, although it is partly responsible for the listing of Houston as similar. The report is based on 56 jurisdictions, which are neither the largest jurisdictions (New York City and San Diego are missing), nor randomly selected. In half of these jurisdictions, homicide rose from 2005 to 2006, and in half it fell—precisely the result one would expect from noise in an unchanging environment. Overall in these jurisdictions homicides rose by 3.1% from 2005 to 2006, possibly not much larger than the increase in population. The report does indicate that a few cities experienced large increases in homicides from 2005 to 2006. Among the large cities in figure 2 and also in the PERF report, Houston (11.9%), San Antonio (36.8%), and Atlanta (20.2%) had double digit increases from 2005 to 2006. (Note that all of these cities are in the general vicinity of New Orleans.) On the other hand, of the figure 2 cities, Dallas (-7.1%), Los Angeles (-1.0%), Milwaukee (-15.6%), St. Louis (-1.5%), and Washington (-13.3%) had fewer homicides in 2006 than 2005.

The rise in murders appears to be a *New Jersey* urban trend, not a national urban trend. Except for Paterson, murders in the other traditional ‘Big 6’ cities and Irvington rose as fast as they did in Newark, or faster. Murders did not rise quickly in New Jersey outside these cities. Table

1 provides the details. The numbers involved here are generally subject to a greater proportion of noise than the numbers for the large cities nationally.

Table 1: Percentage Increase in Murders, 1998-99 to 2004-05, New Jersey Cities

Newark	37.3%
Greater Newark (Newark, East Orange, Irvington)	51.1%
Jersey City	45.7%
Paterson	0.0%
Elizabeth	28.6%
Camden	53.7%
Trenton	113.0%
Everything outside Greater Newark	47.2%

The contrast between New Jersey cities and the large cities outside New Jersey is stark. Except for Paterson, all cities had increases in murder, and except for Paterson and Elizabeth, all increases larger than the increases in Newark. (The largest increase was in Trenton, because of a very large number of murders in 2005; 2006 saw a substantial reduction in murders in Trenton. First half data for 2006 indicate essentially no change in Elizabeth and Paterson and a modest decrease in Jersey City.)

Table 2 summarizes a longer time series, but gives the same picture of discordance with the rest of the nation.<sup>7</sup> Looking at the period 1977-2005, no New Jersey city reaches its trough after 2000, although the national rate is at its trough in 2000 and 2004. Newark and Jersey City are the last two cities to bottom out in New Jersey. These two cities and Paterson fall from peaks in the late 1970s or early 1980s, like the national rate. Camden and Elizabeth have peak years in 1995, well after the national rate and the big cities began to fall, while for Irvington, East Orange, and Trenton the record high years for murders have occurred during the post-2000 upsurge.

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<sup>7</sup>1980 is not available for any city except Newark, and 1990 is available only for Newark and U.S. (Source: FBI, Uniform Crime Reports).

Table 2: Peak and Trough Years for Murders in New Jersey Cities, 1977-2005

	Peak	Ratio to 2000	Trough	Ratio to 2000
Newark	1980	2.80	1997	0.97
Irvington	2005	2.33	1978	0.17
East Orange	2003	1.83	1984	0.58
Jersey City	1979	2.72	1999	0.83
Paterson	1981	2.41	1996	0.41
Elizabeth	1995	1.50	1984	0.25
Trenton	2005	2.21	1985, 91	0.50
Camden	1995	2.42	1985	0.50
U.S. (rate)	1980	1.85	2000, 04	1.00

### 3 The Mechanics of Murder in Newark

The modal Newark murder today occurs late at night or early in the morning; the weapon is a gun; and the victim is an African-American man, usually with some sort of connection to drugs and gangs, but not one that can be readily ascertained or easily articulated. In this section, we show that these are the marginal murders, not just the modal ones, and we argue that they increased mainly because would-be murderers became more lethal in a variety of dimensions. This section is based on Newark Police Department homicide and shooting logs.

#### 3.1 Who?

Table 3 shows that murder victims in Newark are predominantly African-American men, and almost all of the increase in murders has been among this group. (The large number of “other” victims in 2001 primarily reflects incomplete recording.) The overall increase in murder victimization over the period 2000-2005 was 39, or 98% for black males and 1, or 6% for everyone else. While murder has increased among all age groups of African-American men, the largest increase has been among men over 30. This is consistent with stories about returning prisoners, and not consistent with stories about wild teenagers.

Table 3: Demographics of Murder Victims, 2000-2006 (Under 12 included in “other”)

	Black Males			Black Females	Hispanic Males	Hispanic Females	Other
	12-18	19-30	30+				
2000	4	27	9	5	3	2	8
2001	5	33	10	10	12	2	23
2002	2	20	15	6	14	2	8
2003	5	32	22	12	9	0	3
2004	6	43	14	9	19	3	0
2005	10	44	25	6	9	0	4

### 3.2 When and Where?

The great majority of murders occur late at night and early in the morning, and the bodies are discovered on streets. There was little change in these patterns during the rise in murders, although early morning rose somewhat at the expense of daytime.

### 3.3 Why?

The NPD homicide log contains a short description of the motive for many murders (sometimes, of course, nothing is known for sure except that a body was found). Table 4 shows how these ascribed motives have evolved as murder has increased.

Table 4: Newark Murders by Motive, 2000-2006

	Gang	Dispute	Drugs	Domestic Violence	Robbery	Unknown	Other	Total
2000	13	3	5	5	2	27	3	58
2001	14	12	7	9	8	41	4	95
2002	14	5	5	4	5	30	4	67
2003	16	10	0	9	4	39	5	83
2004	29	8	12	9	5	19	12	94
2005	24	33	21	4	11	1	4	98

“Gang” means murders believed to directly further a gang’s objectives, and not otherwise classified as “drugs” or “disputes.” “Disputes” includes murders where the parties are believed to

be engaged in a conflict, but the police are unsure about what—it could be drugs, or women, or money owed, or whether the Nets have a stronger backcourt than the Knicks (even if the parties have gang or drug connections). “Disputes” also includes murders where the police know what the dispute is about, but it is not drugs or gangs. “Domestic violence” includes traditional spousal murders, as well as child abuse, parent abuse, and fights between unmarried couples, gay or straight, who live together.

Disputes are the second most important motive, and rose considerably. This categorization probably understates their prominence, however, since drug, gang, and domestic violence murders are also disputes. Taken together, these categories account for a substantial proportion of murders: 31-36% over the 2000-2003 period, 52% in 2004, and 80% in 2005. They also account for much of the growth in murder, rising by 135% if one compares the 2000-2001 average to the average in 2004-2005. What the large number of murders in the disputes category tell us is that the contentions that end with murder arise over a wide array of matters, not just drugs and gangs. “Disputes” also indicates that most murders happen in a context of *bilateral* animosity: both killer and victim have reason to wish ill for the other, even before the crime occurs.

### 3.4 How?

Both the marginal and the modal murder in Newark is accomplished by gunshot. The number of non-gunshot homicides shows no trend between 2000 and 2006. Table 5 provides the details.

Table 5: Murders by Gunshot Wound in Newark, 2000-2006

	Gunshot	Other	Total
2000	41	17	58
2001	57	38	95
2002	49	18	67
2003	39	44	83
2004	74	20	94
2005	85	13	98
2006	91	14	105

We can examine the reasons why gunshot homicides rose in more detail. Newark police keep detailed records on gun discharge incidents, and so we can investigate how gunshot murders rose.

Newark investigators sort gun discharge incidents into three categories. ‘Shooting-hit’ ( $S_h$ ) is an incident in which a bullet wounds a person, but not fatally. ‘Shooting-no hit’ ( $S_{nh}$ ) is an incident in which a bullet is fired at a person, but does not hit him. ‘Shots fired’ ( $S_f$ ) is an incident in which a gun is fired, and investigators do not know whether the shooter had an intended victim or sought only to send a message of ill-will or warning. (Since shooting-no hit is distinguished from shots fired through an assessment of intention by an acknowledged victim or a police officer, many economists might prefer to ignore this distinction, because in all these incidents the shooter does something that increases somebody’s probability of death. Accordingly, we perform all analyses in a way that allows readers to choose for themselves how to consider ‘shots fired’.) The record is of *incidents*, not of gun discharges. A single incident may involve many shots. We define “gross gun discharge incidents” as the sum of gun discharge incidents and gunshot homicides ( $H$ ). Sometimes we will refer to gross gun discharge incidents simply as “shootings” ( $S$ ).

Our first attempt to understand why gun homicides rose is to decompose the transition from gross gun discharge incidents to gun homicides into several steps of increasing seriousness. By definition:

$$H = S - S_f - S_{nh} - S_h,$$

which yields the following identity:

$$\log H = \log S + \log \left( \frac{S - S_f}{S} \right) + \log \left( \frac{S - S_f - S_{nh}}{S - S_f} \right) + \log \left( \frac{S - S_f - S_{nh} - S_h}{S - S_f - S_{nh}} \right).$$

The second term on the right hand side we call the *intention ratio* (the proportion of shots with intention to hit someone); the third term the *hit ratio* (the proportion of shots with intention that actually hit); and the third the *kill ratio* (the proportion of shots that hit that killed). Taking changes in these terms over time lets us see how much of the increase in gun homicides was due to more shootings, how much to a higher intention ratio, how much to a higher hit ratio, and how much to a higher kill ratio. Table 6 carries out this decomposition.

Gun homicides increased by nearly 80 log points between 2000 and 2006, but shootings increased by only 14 log points. “More shootings” is a small part of the story of more homicides. A higher proportion of shootings had intent to hit someone, and a higher proportion did hit someone, but the major story is that the probability of a murder conditional on a hit rose: 56% of the log rise in gun homicides is due to the higher conditional probability of death conditional on being hit by a gunshot. Murders rose mainly because shootings became more deadly, especially shootings where someone was wounded.

Table 6: Decomposition of Gun Homicides in Newark (all magnitudes in natural logs)

	Shootings	Intention	Hit	Kill	Gun Homicides
2000	6.402	-0.451	-0.250	-1.987	3.714
2001	6.337	-0.429	-0.181	-1.684	4.043
2002	6.277	-0.469	-0.156	-1.761	3.892
2003	6.349	-0.378	-0.142	-1.751	4.078
2004	6.486	-0.411	-0.127	-1.644	4.304
2005	6.553	-0.400	-0.146	-1.564	4.443
2006	6.537	-0.357	-0.130	-1.539	4.511
2006-2000	0.135	0.094	0.120	0.448	0.797
Share	17%	12%	15%	56%	100%

Why did shootings become more deadly? Several answers are possible, and we can use the NPD homicide log and the shooting log to sort some of them out. Possible answers are: (i) potential murderers acquired better weapons that let them fire more frequently and so a higher proportion of gross gun discharge incidents involved multiple shots, (ii) potential murderers acquired higher caliber weapons that were more likely to kill when they did not make direct hits, (iii) potential murderers acquired more skills, (iv) potential murderers exerted more effort in trying to kill their victims (for instance by standing closer to the victim or driving by more slowly), and (v) emergency medical care became less effective. These reasons have different implications for policy, as we shall see.

We can gain some information about why shootings become more deadly from notation in the Newark homicide log.<sup>8</sup> Our calculations are described in the Appendix. These calculations suggest that gunshot homicides increased in Newark because more gross gun discharge incidents involved multiple shots, possibly because of the presence of more semi-automatic weapons, because higher caliber weapons were used, and because marksmanship improved. Our models are too crude for us to have confidence in the exact attribution, but each of these factors seems to have made a significant difference. Shootings became more deadly in all dimensions.

For policy and prediction purposes, an important distinction is between irreversible investments—greater skill and better hardware to the extent that resale is difficult—and transitory effort. Irre-

<sup>8</sup>NPD files give us no direct information about emergency medicine, but below we show that it probably did not play a role in the rise in murder.

versible investments make lethality cheaper in the future, and thus contain the seeds of hysteresis, but transitory effort does not. Our analysis suggests that both irreversible investment and effort contributed to the rise in gun homicide. Hysteresis is going to be a problem in reducing murders, but not an overwhelming one. Our next task is to ask why potential murderers in Newark made these investments and undertook this effort. We need a formal model to do this.

## 4 A Model of Preemptive Murder and Endogenous Lethality

### 4.1 Preliminaries

We have seen that most murders in Newark occur in circumstances where two parties bear some mutual animosity—disputes, gang fights, drug deals gone bad—and each may gain from the other’s death. (Ex post, certainly, the victim would have been better off had he killed his murderer first.) For ease of exposition we assume that the parties to the conflict are *ex ante* identical (their characteristics drawn from the same probability distribution), although our results do not depend on this symmetry assumption.

We use the term "interaction" to describe a dispute between two individuals that could potentially result in murder. This term should be interpreted broadly. It could be a fleeting exchange of fire lasting just a few seconds, or an extended feud, with the parties trying to ambush each other at opportune moments. Thus a single interaction may spawn numerous unilateral gross gun discharge incidents over a period of many months. Indeed, victims almost never have guns in their possession when the police arrive. Sometimes the guns have been stolen after their death, but in many cases the victims had access to guns but were not carrying them when they were attacked.

Two types of weapon are available, one more lethal than the other. We define the lethality of a weapon to be the probability that its use in a single shooting incident will kill its target, when the target is unarmed. Let  $\alpha$  and  $\beta$  denote the two available levels of lethality, with  $\beta > \alpha > 0$ . Individuals may endow themselves with either one of these weapons, or remain unarmed. The cost of acquiring the more lethal weapon is denoted  $c$ , and the less lethal weapon is assumed for simplicity to be costless.

"Two types of weapon" should not be interpreted literally as an assumption about hardware. The assumption is that there are two ways to try to kill someone, and the more lethal one is more expensive in some way. Thus the contrast could be between standard guns and semi-automatics that permit more shots in an incident, between small caliber guns and large caliber guns, between

being untrained and being a skilled marksman, between firing while driving by at high speed and shooting point blank on the sidewalk, or between making little effort with haphazard fire and cool concentrated and close mayhem. The previous section suggested that murderers in Newark raised lethality by making all of these adjustments.

The probability that an individual is killed in any given interaction depends not only on the lethality of his opponent's weapon, but also the lethality of his own. We assume that at most one individual is killed in any given interaction, and let  $p(x, y)$  denote the probability that a player using lethality  $x \in \{0, \alpha, \beta\}$  is killed when his opponent uses lethality  $y \in \{0, \alpha, \beta\}$ . Then  $p(0, y) = y$  and  $p(x, 0) = 0$  by definition. We assume that  $p(x, y)$  is decreasing in its first argument and increasing in its second: other things equal, a player is more likely to be killed if his opponent uses a more lethal weapon, or if he himself uses a less lethal one. The rationale for the latter assumption is that a player who shoots first and misses may face return fire, and possession of a less lethal weapon makes this scenario more likely.

An example of an interaction structure that gives rise to a specific function  $p(x, y)$  with these properties is the following. Suppose that each of the two players has at most one opportunity to shoot, and that they fire in sequence. Each player faces probability one-half of being the first to shoot. If the first shooter hits his target the interaction ends. If not, the targeted individual shoots back, at which point the interaction ends regardless of the outcome. In this case

$$p(x, y) = \frac{1}{2}y + \frac{1}{2}(1-x)y = \frac{1}{2}y(2-x). \quad (1)$$

We revisit this particular interaction structure in more detail below, but for the moment retain the more general formulation.

If neither player is killed, their payoffs are each normalized to 0. Otherwise the victim's payoff is  $-\delta$  and the shooter's payoff  $-\gamma$ . This latter payoff reflects in part the likelihood of arrest and prosecution, and the severity of the subsequent sentence. It also reflects the gains he realizes (other than his own survival) from the other party's death, as well as such factors as mood, anger, and the consumption of alcohol or drugs. Suppose that  $\delta > 0$  and is commonly known, but  $\gamma$  is private information, drawn (independently across players) from a probability distribution with full support on the real line  $\mathbf{R}$ . Hence there are some individuals whose disutility  $\gamma$  from successfully shooting someone is negative, even taking into account the risk of incarceration. The distribution function, which we assume to be continuously differentiable, is denoted  $F(\gamma)$ , and the corresponding density function is  $f(\gamma)$ .

If a player with cost  $\gamma$  chooses lethality  $x$  and is confronted by someone choosing lethality  $y$ , his payoff is

$$\pi_{xy}(\gamma) = -p(x, y)\delta - p(y, x)\gamma. \quad (2)$$

This is the payoff from the interaction itself, and does not include the cost  $c$  that is incurred if  $x = \beta$ . Given  $c$ ,  $F(\gamma)$  and  $p(x, y)$ , (2) defines a Bayesian game in which each player chooses an action  $x \in \{0, \alpha, \beta\}$  contingent on the value of his (privately observed) cost  $\gamma$ . Let  $s(\gamma)$  denote a player's strategy, where  $s : \mathbf{R} \rightarrow \{0, \alpha, \beta\}$ .

Suppose that a player believes that his opponent will use lethality  $\alpha$  with probability  $\lambda$ , and lethality  $\beta$  with probability  $\mu$ , where  $\lambda + \mu \leq 1$ . Then the expected payoff from choosing action  $x$  is

$$\pi_x(\gamma) = -(1 - \lambda - \mu)\gamma x - \lambda(p(x, \alpha)\delta + p(\alpha, x)\gamma) - \mu(p(x, \beta)\delta + p(\beta, x)\gamma)$$

A strategy  $s^*(\gamma)$  corresponds to a symmetric Bayes-Nash equilibrium if the beliefs  $(\lambda, \mu)$  of the players are correct conditional on the fact that they both adopt  $s^*(\gamma)$ , and  $s^*(\gamma)$  is a best response to those beliefs (taking account of the cost  $c$  if lethality  $\beta$  is chosen).

As long as the cost of high lethality is not too small, there is at least one symmetric equilibrium  $s^*(\gamma)$ . Furthermore, any such equilibrium has the following partitioned structure: the lowest cost individuals choose lethality  $\beta$ , the highest cost individuals remain unarmed, and a set of individuals with intermediate costs choose lethality  $\alpha$ . This may be stated more formally as follows.

**Proposition 1.** *There exists  $\tilde{c} \geq 0$  such that for all  $c > \tilde{c}$ , there exists at least one symmetric equilibrium  $s^*(\gamma)$ . Any such equilibrium has the following structure: there exist  $\gamma_1$  and  $\gamma_2$  such that  $\gamma_1 < \gamma_2$  and  $s^*(\gamma) = \beta$  for  $\gamma < \gamma_1$ ,  $s^*(\gamma) = \alpha$  for  $\gamma \in (\gamma_1, \gamma_2)$ , and  $s^*(\gamma) = 0$  for  $\gamma > \gamma_2$ .*

Let  $\omega = \lambda\alpha + \mu\beta$  denote the likelihood of being killed conditional on being unarmed, and let  $c' = c/(\beta - \alpha)$  denote the cost of switching from  $\alpha$  to  $\beta$  normalized by the resulting increase in lethality. For the specific case of the interaction structure that gives rise to equation (1), the thresholds  $\gamma_1$  and  $\gamma_2$  can be expressed as simple functions of  $\omega$  and  $c'$ , and a symmetric equilibrium exists for any positive cost  $c$ .

**Proposition 2.** *Suppose that  $c > 0$  and  $p(x, y)$  satisfies (1). Then there exists at least one symmetric equilibrium  $s^*(\gamma)$ . Any such equilibrium has the following structure:  $s^*(\gamma) = \beta$  for  $\gamma < \gamma_1$ ,  $s^*(\gamma) = \alpha$  for  $\gamma \in (\gamma_1, \gamma_2)$ , and  $s^*(\gamma) = 0$  for  $\gamma > \gamma_2$ , where*

$$\gamma_1 = \frac{\delta\omega - 2c'}{2 - \omega} \text{ and } \gamma_2 = \frac{\delta\omega}{2 - \omega}. \quad (3)$$

*In any interaction, the likelihood of a murder is  $\omega(2 - \omega)$ , the expected value of gun discharges is  $(\lambda + \mu)(2 - \omega)$ , and the ratio of murders to gun discharges is therefore  $\omega/(\lambda + \mu)$ .*

We shall refer to  $\omega$  as the level of *danger*. Since this is an endogenous variable, equations (3) are consistent with the occurrence of multiple equilibria. However, since  $\omega$  uniquely determines the thresholds  $\gamma_1$  and  $\gamma_2$ , it also uniquely determines the probabilities  $\lambda$  and  $\mu$  with which the levels of lethality  $\alpha$  and  $\beta$  are used. Hence there can be at most one equilibrium corresponding to any given value of equilibrium danger  $\omega$ . We next explore conditions under which multiple equilibria exist.

One can also think of  $\omega$  as the level of "tension," to use the term often used by police to describe the situation that prevails before murders. When people are tense, they jump to respond to any provocation or danger, real or imagined. Tension begets murders, and murders in turn raise tension. In this sense, our model can be interpreted as an analysis of equilibrium tension.

## 4.2 Multiplicity of Equilibria

One of the key questions here is the manner in which changes in the distribution of costs  $F(\gamma)$  affect the set of equilibria. To this end, we introduce a shift parameter  $a$  and write the distribution of costs as  $F(\gamma, a)$ . We adopt the convention that for any pair  $a, a'$  satisfying  $a > a'$ , we have  $F(\gamma, a') > F(\gamma, a)$ . That is, a decrease in  $a$  shifts the distribution to the left, corresponding to an overall decline in the expected costs of attempted murder (or an increase in the expected gains, not including survival). Such a shift could be induced, for instance, by a decline in the effectiveness of the criminal justice system.

The following example illustrates the possibility that a small decline in  $a$  can cause large and discontinuous changes in the level of lethality chosen and in the murder rate.

**Example 1.** Suppose that  $\alpha = 0.2$ ,  $\beta = 0.6$ ,  $\delta = 20$ ,  $c = 1$ ,  $p(x, y) = y(2 - x)/2$ , and  $\gamma$  is normally distributed with variance 1 and mean  $a$ . If  $a = 1.03$  there exist three equilibria with levels of danger  $\omega = 0.18$ ,  $\omega = 0.23$ , and  $\omega = 0.60$  respectively. If  $a = 1.02$ , however, there is a unique equilibrium with  $\omega = 0.60$ .

This example illustrates that a small shift in the cost distribution can result in a large, discontinuous change in equilibrium danger. Figure 3 shows how the entire set of equilibria varies with  $a$  over the range  $[0.9, 1.4]$  for the specification used in Example 1. (Note that the horizontal axis is reversed.)

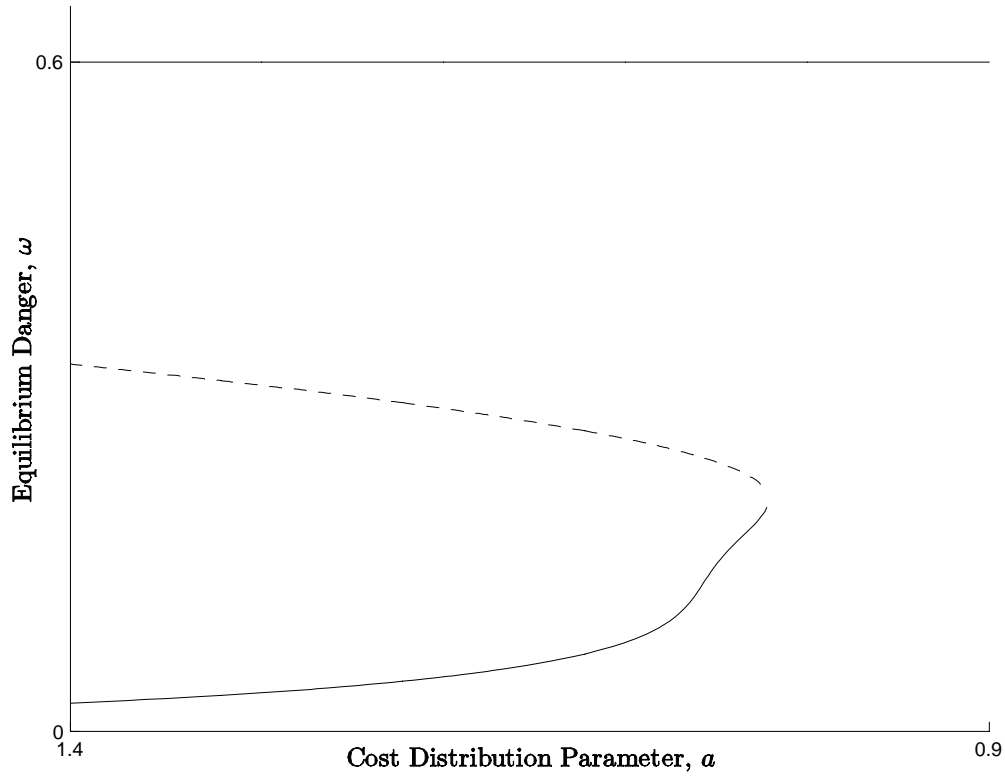


Figure 3. Effects of changes in  $a$  on the set of equilibria.

Suppose that one begins on the lower arm of the equilibrium set and  $a$  declines to the point at which equilibrium becomes unique. It is useful to see what happens at the point of discontinuity to the level of danger  $\omega$ , the murder rate, gross gun discharge incidents, the proportion  $\lambda$  using lethality  $\alpha$ , the proportion  $\mu$  using lethality  $\beta$ , and the proportion  $1 - \lambda - \mu$  who remain unarmed. These shifts are depicted in Figure 4. As the threshold value of  $a$  is crossed, the level of danger jumps up discontinuously as both the unarmed and the individuals using lethality  $\alpha$  switch to the higher lethality  $\beta$ . The use of the less lethal weapon collapses to practically zero, as does the proportion of the population who choose to remain unarmed. The murder rate rises discontinuously, but total gun discharges *decline*. This is because the higher level of lethality results in lower victim survival and hence a reduced likelihood of a retaliatory strike. More generally, the effect of a rise in  $a$  on shootings is theoretically ambiguous.

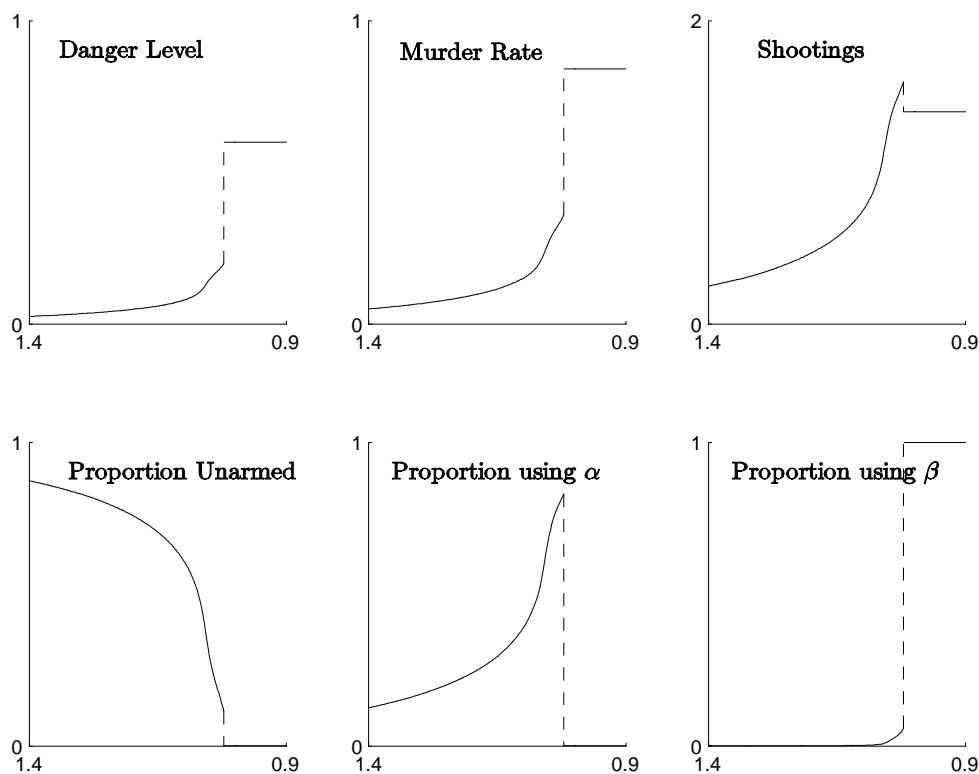


Figure 4. Equilibrium danger, murder, gun discharges, and weapon choice.

Notice that even before the point of discontinuity is reached, the level of danger and the rate of high lethality begin to rise at an increasing rate. As the environment becomes more dangerous, more parties switch to higher lethality, which in turn makes the world more dangerous. Danger is increasing not only because there are more violent people, but also because people who were formerly nonviolent are switching to violence. The number of murders also grows more quickly, but the number of gross gun discharge incidents does not increase as rapidly as the number of murders. This is because greater lethality makes it more likely that feuds will end quickly. This is consistent with the Newark experience we described in the previous section.

### 4.3 The Murder Multiplier

Many analyses of murder (and other crimes) do not take game-theoretic considerations into account. They work with a single-actor decision problem and ask what would make a person viewed in isolation more or less likely to commit murder. To link our approach to that literature, we ask what levels of shooting would prevail if no party had a preemption motive.

This is equivalent to asking what level of lethality would be chosen by an actor who was certain that his opponent was unarmed. Using (2), such an individual would choose lethality 0 if  $\gamma > 0$ , and

lethality  $\beta$  if  $\gamma < -c'$ . If  $0 > \gamma > -c'$ , then lethality  $\alpha$  is chosen. Accordingly, we define autonomous shooting probabilities as follows:  $\tilde{\lambda} = F(0) - F(-c')$ , and  $\tilde{\mu} = F(-c')$ . The autonomous level of danger is then  $\tilde{\omega} = \alpha\tilde{\lambda} + \beta\tilde{\mu}$ .

The analogy is with autonomous expenditure in the simple Keynesian model of goods market equilibrium. In that model equilibrium expenditure is greater than autonomous expenditure because of strategic complementarity: more autonomous spending by the government, say, induces consumers to spend more, which induces other consumers to spend more, and so on. The ratio of equilibrium to autonomous expenditure is the multiplier. In our model there is a murder multiplier that also operates through strategic complementarity, and makes equilibrium murders greater than autonomous murders. More precisely, we can prove that the autonomous shooting probability  $\tilde{\lambda} + \tilde{\mu}$  is always less than the shooting probability in *any* equilibrium, and if the cost of victimization  $\delta$  is sufficiently high, then the autonomous level of danger  $\tilde{\omega}$  is always less than any equilibrium level of danger. It follows that autonomous murder is less than equilibrium murder.

**Proposition 3.** *Consider any equilibrium, and let  $(\lambda^*, \mu^*)$  denote the equilibrium rates of use of  $\alpha$  and  $\beta$  weapons respectively and  $\omega^*$  the corresponding level of danger. Then  $\lambda^* + \mu^* > \tilde{\lambda} + \tilde{\mu}$  and if  $\delta$  is sufficiently high,  $\omega^* > \tilde{\omega}$ .*

In the special case when (1) holds, it can be shown that  $\delta \geq c'$  is a sufficient condition to ensure that  $\omega^* > \tilde{\omega}$ . This is a very weak condition, requiring only that the cost of murder victimization exceed the unit cost of greater lethality. Moreover, since the murder rate is increasing in the level of danger, equilibrium murders exceed autonomous murders when this condition is met.

Somewhat surprisingly, the preemptive motive can actually reduce murders relative to the decision-theoretic benchmark if  $\delta$  is sufficiently small. The reason is that the game theoretic equilibrium takes into account the possibility that if one is shot before one can shoot, the lethality of one's weapon becomes irrelevant, and a costly investment in greater lethality is wasted. Possession of a more lethal weapon does make it less likely that one is shot, but when  $\delta$  is small this provides a negligible incentive to invest.

#### 4.4 Comparative Statics

The example above shows that a decline in  $a$  can cause the equilibrium set to change in a manner that results in discontinuous increases in lethality and danger. Similar effects can arise as a result of changes in other parameters of the model. To show this, we again consider the interaction structure

resulting in equation (1), which implies equilibrium thresholds that satisfy (3). Any equilibrium of this model can be characterized as follows.

**Proposition 4.** *Suppose that  $c > 0$  and  $p(x, y)$  satisfies (1). Then there exists a strictly increasing function  $\varphi : [0, \beta] \rightarrow [0, \beta]$  such  $\omega = \varphi(\omega)$  if and only if  $\omega$  is an equilibrium level of danger. The function  $\varphi(\omega)$  is decreasing in  $a$  and  $c$ , and increasing in  $\beta$  and  $\delta$ .*

The function  $\varphi(\omega)$  identified in this result may be viewed as a best response function: if individuals choose optimal strategies based on the belief that the level of danger is  $\omega$ , then the realized level of danger will be  $\varphi(\omega)$ . The fact that optimal strategies depend only on  $\omega$  (and not on the underlying values of  $\lambda$  and  $\mu$ ) makes this case especially tractable. We show in the proof of Proposition 4 that  $\varphi(\omega)$  is given by

$$\varphi(\omega) = \alpha F\left(\frac{\delta\omega}{2-\omega}\right) + (\beta - \alpha) F\left(\frac{\delta\omega - 2c'}{2-\omega}\right) \quad (4)$$

Note that by definition, the level of autonomous danger is  $\tilde{\omega} = \varphi(0)$ .

As an example, suppose that  $\gamma$  is normally distributed with mean  $a$  and variance 1, and all parameter values are as in Example 1. Figure 5 shows  $\varphi(\omega)$  for two different values of  $a$ . When  $a = 1.5$  there are three equilibria. Declines in  $a$  (which correspond to a shift to the left in the cost function) shift  $\varphi(\omega)$  upwards. At some value of  $a$  the equilibrium set contracts in size and there is a unique equilibrium with a high level of danger.

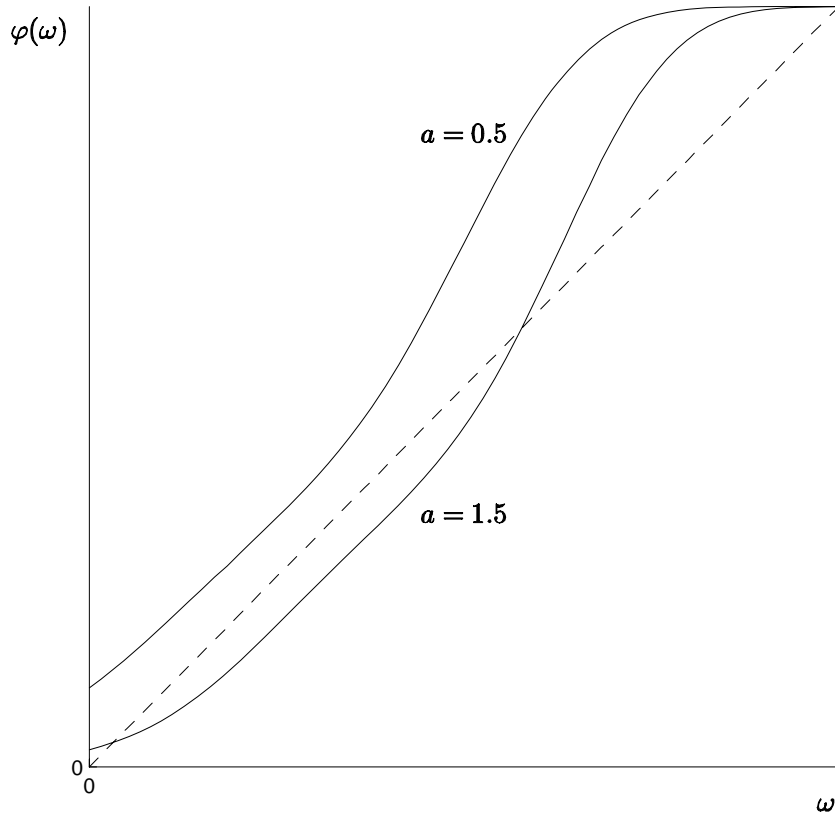


Figure 5. The function  $\varphi(\omega)$  for two values of  $a$ .

In general, any change in the primitives of the model that causes the function  $\varphi(\omega)$  to shift upwards can result in the kind of effect identified in Figure 5, with discontinuous changes in equilibrium danger and the lethality and extent of weapon use. From Proposition 4, a discontinuous rise in equilibrium danger can be triggered by (i) a shift to the left in the net penalty distribution  $F(\gamma)$ , (ii) a decline in the cost of high lethality  $c$ , (iii) an increase in the disutility of victimization  $\delta$ , or (iv) an increase in the highest level of feasible lethality  $\beta$ . These effects are all intuitive in sign, given the importance of the preemptive motive for murder. In each case, a small parameter shift can give rise to a cascade of expectations resulting in sharp increases in danger. While the initial (disequilibrium) effect of the change may be small, individual responses to the change induce even greater responses from others.

The effect on equilibrium danger of increases in  $\alpha$  are ambiguous. On the one hand, murders increase because those choosing lethality  $\alpha$  are more likely to strike their targets. On the other hand, the narrowing of the gap between  $\beta$  and  $\alpha$  raises the effective price of lethality  $c'$ , and induces fewer individuals to adopt the more lethal weapon. Hence, somewhat paradoxically, a rise in the lethality of some weapons, holding constant the lethality of others, can result in reduced equilibrium

danger.

To summarize, the sharp increase in murder rates could have been triggered by one or more of the following: the availability of weapons of greater lethality or lower cost, a greater aversion to being victimized (which encourages preemptive first strikes), or a general decline in the expected penalties faced by offenders. The key point is that a small change in any of these parameters can give rise to sharp, discontinuous changes in murder rates due to the cascading effect of expectations coupled with the preemptive motive for killing.

#### 4.5 Peaceable kingdoms and war zones

In most of the US most of the time, murder is a rare event. A non-Hispanic white woman was about 3.7 times as likely to die from an unintentional fall in 2002 as to be murdered (Minino et al. 2006, table 9). How can we account for this fact in our model? The basic reasons why murder is rare most of the time are that the autonomous level of murder is low, and that at the autonomous level of murder, few people are on the margin. For most people most of the time there is not much to be gained from murdering someone, compared with the psychic and legal penalties that are likely to follow. If  $\tilde{\omega} = \varphi(0)$  is very small and the  $\varphi(\omega)$  curve is very flat, then there will be a stable internal equilibrium very close to 0 (see Figure 5).

Note that from (4), we have

$$\varphi'(\omega) = \frac{2}{(2-\omega)^2} (\alpha \delta f(\gamma_1) + (\beta - \alpha) (\delta - c') f(\gamma_2))$$

If  $f(\gamma_1)$  and  $f(\gamma_2)$  are both very small because almost no one is on the margin between becoming armed and remaining unarmed, then the  $\varphi(\omega)$  curve will be very flat, and there will be a stable equilibrium very close to  $\tilde{\omega}$ . This depends both on the intercept  $\tilde{\omega}$  and the slope  $\varphi'(\omega)$  being small. The first depends on  $F(0)$  and  $F(-c')$  being small; the second on  $f(0)$  and  $f(-c')$  and the density function in their respective neighborhoods being small. Both conditions are probably often met for many modern American communities. We call such communities *peaceable kingdoms*. In such communities, comparative statics on  $\tilde{\omega}$  are a good approximation to comparative statics on  $\omega^*$ , and the standard single-actor analysis is not especially misleading. Thus in most times and places, ignoring preemption is not a serious error.

When the level of danger is great, even at a stable internal equilibrium, the multiplier is large and comparative statics are different from comparative statics on  $\tilde{\omega}$ . Effects usually work in the same direction, but they are magnified. For future reference, we call communities with a lot of

danger and a large multiplier *war zones*.

We can show, in fact, that even at stable internal equilibria, as danger grows the effects of parameter changes grow infinitely large, even before a discontinuous jump to a new equilibrium. To see this, we introduce a shift parameter  $q$  and write the best response function as  $\varphi(\omega, q)$ . Assume that the derivative  $\varphi_2(\omega, q)$  is positive and bounded away from 0 for all  $\omega$  and  $q$ . Define

$$\hat{\omega}(q) = \inf \{ \omega \mid \omega = \varphi(\omega, q) \}.$$

This is the lowest level of danger consistent with equilibrium for any given  $q$ . Then we have

**Proposition 5.** *Suppose that for all  $q$  in some closed set  $[\bar{q}, \hat{q}]$ , we have  $\hat{\omega}(q) < \beta$ , and  $\hat{\omega}(q)$  has a discontinuity at  $\hat{q}$ . Then  $\lim_{q \rightarrow \hat{q}^-} \hat{\omega}'(q) = \infty$ .*

Hence small changes in underlying parameters can give rise to very large effects on equilibrium danger (and hence equilibrium murder) in places that are very violent. War zones are like this, and peaceable kingdoms are not.

## 4.6 Dynamics

What happens when this game is played repeatedly? A fully developed intertemporal model is clearly outside the scope of this paper, but we can point in some general directions. If the cost required to produce lethality is an irreversible investment, then lethality produced in one period reduces the cost of lethality in subsequent periods. Lower cost of lethality in subsequent periods implies more murders in subsequent periods. So if irreversible investments are what produce lethality, murders today increase murders tomorrow, *ceteris paribus*. Examples of irreversible investments include skilled marksmanship and the transaction costs involved in acquiring guns.<sup>9</sup>

This prediction is based on a model of myopic decision-making, but the basic conclusion should be robust. Consider a rational expectations world and a surprise change in fundamentals in period  $t$  that increases equilibrium murder and lethality. The murder shock raises irreversible investments in period  $t$ , and so raises murder in period  $t + 1$ , no matter what period  $t + 1$  fundamentals are. Seen from period  $t - 1$ , expected murders are higher in period  $t + 1$  than if the period  $t$  shock had never occurred. That is, expected  $t + 1$  murders conditional on a positive murder shock in period  $t$

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<sup>9</sup>The relevant cost of using a gun one already owns is the opportunity cost, the money one could make selling or renting it to someone else. But because illegal gun markets have huge transaction costs, this is usually well below the acquisition cost. See Cook *et al.* (2005).

are greater than unconditional expected  $t + 1$  murders. Comparing two communities with the same fundamentals and different histories, the community with more murders in the past will have more murders today.

Selection of agents may also affect intertemporal dynamics. Suppose that net murder costs  $\gamma$  are positively correlated over time within individuals: people with low net costs today are likely to have low net costs tomorrow. Within any population, those with higher  $\gamma$  are more likely to be murdered. Under weak conditions the distribution of  $\gamma$  tomorrow will be stochastically dominated by the distribution today. The population will grow more dangerous over time as less dangerous individuals are weeded out. On the other hand, incarceration could work in the opposite direction.

## 5 Prediction Biases

Criminologists and economists have produced an impressive empirical literature on homicide. This literature can help us understand what set off the rise in Newark murders, and what policies are likely to reverse this trend. The general message of this literature is that fundamentals and incentives matter: police, arrest rates, and incarceration usually reduce murder. Not every paper finds that every incentive matters, but many papers find that these standard variables reduce murder. Murder is not unpredictable.

Our model of preemptive murder, however, indicates that some the estimates of the size of these effects are likely to be too low for Newark in this decade. There are two general reasons. First, as shown in proposition 5 and the related discussion, responses to policies are likely to be greater in situations where the level of danger is high than in situations where the level of danger is low. An equation fitted on a data set where most communities have small murder rates will find much smaller average responses than prevail in communities where danger is high. Studies that report on average responsiveness are likely to underestimate the size of responses in places like Newark. We call this problem *non-linearity prediction bias*.

Second, studies that define narrowly the type of murders that a particular policy is supposed to affect may underestimate the policy's effect for two reasons. They may miss murders outside the narrow circle that they draw that were really affected by the policy, and, worse, they may use these murders that should be inside the circle as a comparison group. For example, suppose we want to study a particular policy targeted at husbands who kill their wives. What happens if we look only at murders committed by husbands? Our preemption model tells us that there is a first-order

bias in this research strategy because if husbands become less likely to kill wives, wives will be less likely to kill husbands. The proper procedure looks at both kinds of spousal murders. The problem is exacerbated if the study uses murders of husbands by wives as a control group. We call this problem *narrow-estimation bias*.

We begin with the arrest rate, since it is the most traditional deterrence variable, and possibly a major part of the Newark story. Levitt (1998) uses panel data for 59 large cities for 1970-1992 to find the effect of arrest rates on various crimes. For most crimes he finds significant effects. But for murder, although some of his equations have significant coefficients, his final preferred conclusion has murder arrests associated with a tiny, insignificant rise in murders.

More recent papers show larger effects. Corman and Mocan (2005) use monthly data for New York City for the period 1974-1999. They used lagged arrests to avoid endogeneity problems, and find significant negative effects comparable to an elasticity of  $-0.4$ . In an earlier paper, Corman and Mocan (2000) use data for a slightly different period, but still find approximately the same elasticity.

Finally, Dezhbaksh, Rubin, and Shepherd (2003, hereafter DRS) use panel data for 3054 counties for the period 1977-1996. They estimate a system of equations by 2SLS. The arrest rate is endogenous, but enters into the murder equation. They find a large and significant negative effect. Since most counties most of the time are peaceable kingdoms, these estimates are likely to be affected by non-linearity prediction bias.

The effects of prison population are also included in many studies. Many of these, especially those using state or state-level data found no effect on murder. Zimring and Hawkins (1995) looked at a California time series in the 1980s, and Marvell and Moody (1994) used a panel of states. Levitt, Katz and Shustorovich (2003) also use state panel data for 1950-1990; they do not find a significant effect of prisoners per capita on murder, but they do find that states with more noisome prison conditions, as proxied by prisoner deaths, have fewer murders.

Levitt (1996) is the most famous study of the effect of prison population on crime. With state data, he uses court-ordered releases as an instrument, and finds significant effects (fewer prisoners, more crime) for most index crimes, but not for murder. State authorities may have been clever enough to preclude the release of would-be murderers when they faced these orders. More plausibly, remember that in war zones, the threshold  $\gamma$  at which murder is committed is higher than in peaceable kingdoms. (This always holds for the threshold for attempting murder with  $\alpha$ -lethality and usually holds for the threshold for attempting murder with  $\beta$ -lethality.) Many

marginal prisoners may often be between these two thresholds—they are neither homicidal maniacs (who would stay in prison almost always) nor choir boys (who would not be in prison in the first place). Thus reductions in prison population would raise murders in war zones, but not in peaceable kingdoms. Since most communities are peaceable kingdoms, Levitt’s study could have missed the effect in war zones.

On the other hand, researchers using national data have found effects of prison population on murder. Bowker (1981) and Cohen and Land (1987) found modest effects. Devine et al. (1988) and Marvell and Moody (1997) use national time series for very long periods and find elasticities greater than one in absolute value. The latter paper argues that OLS is appropriate because murderers are a small part of prison population, and shows that murder does not Granger-cause prison population.

Our model suggests a reason why national time series data find large effects for prison population and state-level panels do not. Suppose most states are peaceable kingdoms and a few are not, but a large proportion of murders take place in the few that are not. Prisoners have a minuscule effect in peaceable kingdoms, but a large effect in war zones. Then national data, being aggregates, are dominated by the war-zone effects, while the state panels are dominated by the peaceable kingdom effects. (Marvell and Moody (1997) try to explain the difference by interstate migration.)

Corman and Mocan (2005) also look at prison population in their analysis of New York City. Their explanatory variable is total prisoners from New York City, and they find a significant though small coefficient of  $-.08$ . Raphael and Stoll (2004) also use state panel data, but they consider prisoner releases and prisoner commitments separately. For murder, they find that the effect of a prisoner release is very close to the effect of a prisoner commitment, but opposite in sign. Thus changes in murder should depend approximately on changes in prison population, however they occur. Their estimates imply that a reduction of 1000 in prison population, lagged a year, raise murders by between 11 and 28.

A number of papers also have results about police strength. Levitt (2002) uses a panel of 122 cities from 1975 to 1995. In his most convincing version he uses firefighters as an instrument for police officers. He finds a significant elasticity of  $-0.9$ , which is larger than the elasticity of any other crime except motor vehicle theft. DRS use police expenditures in their 2SLS system, and find an indirect effect on murder, but do not report the magnitude. On the other hand, Corman and Mocan (2000, 2005) in both of their papers include police strength as an explanatory variable, but it does not have a significant effect on murder in either. Dezhbaksh and Shepherd (2006) also found no significant impact of police expenditures on murder. They used a panel of states for the

period 1960-2000. Since most police do not work on homicides, these negative results may not be surprising. Levitt believes his instrumental variable picks up cities with a culture that promotes spending on public safety; such a culture may produce large investments in homicide squads and training, even holding the total size of the police force constant. So the instrument may have more information about how much effort is devoted to murder than day-to-day changes in total police strength.

Finally, we should note the Glaeser and Sacerdote (1996) is a paper directly related to ours in that it tries explain the huge intertemporal and interspatial variance of crime rates by appealing to social interactions. They conclude, however, that the amount of social interaction is “almost negligible in murder and rape,” although it is much greater for petty property crimes. Our fundamental difference with Glaeser and Sacerdote is how they measure social interactions. Their model has two types of people: those who can be influenced to commit crime by whether their neighbors commit crime, and those who cannot. (Influence in their model is contagion or imitation, not self-protection as in our model.) Their measure of social interaction is the proportion of people in the entire population who can be influenced in the average jurisdiction. In a sense their findings are a confirmation of our assertions about peaceable kingdoms. Perhaps it would be more relevant for murder to measure social interactions by the proportion of people who can be influenced relative to the proportion committing the crime, not the entire population.

## **6 What happened in Newark?**

Our story is simple: murders rose in Newark because criminal justice became less effective in several dimensions more or less simultaneously, and this set off a cycle where more people began killing for their own safety. The rise in murders was larger than the empirical literature predicts, but non-linearity prediction bias could be at work. Several other factors, such as falling conviction rates and state prison segregation policies may also have mattered.

In this section, we will first argue that the model of preemption and increasing lethality that we developed in section 4 is consistent with Newark’s experience. Then we document the deterioration of criminal justice, and discuss how much of an increase in murder this may have caused. Finally we look at some other possible explanations.

## 6.1 Congruence with the Preemption Model

The obvious testable implication of the preemption model is that the ratio of murders to gross gun discharge incidents should rise as murders rise. Clearly this has been the case in Newark. Recall that the model predicts greater lethality even if the rise in murders is caused by deteriorating deterrence or a toughening of the population distribution. The type of guns that potential murderers use can change even if the relative price and availability of high quality guns stays the same.

An easy extension of the model to a world where people have many different ways, places, and times to kill each other also generates some testable propositions. First, suppose that agents have many different ways in which they can increase lethality, instead of just one. Then an increase in murder and lethality driven by deterrence deterioration is likely to use all available means of lethality enhancement—partly because of heterogeneity among agents, and partly because of diminishing marginal returns. Again, that is what we see happening in Newark.

Second, suppose that agents have many different times and places at which to try to kill their victims. Then we would expect to see the increase in gross gun discharge incidents spread fairly uniformly over times and places—not only because of heterogeneity and diminishing marginal returns, but also because stalking a victim has elements of a zero-sum two-person game where randomization is often part of the optimal equilibrium strategy. Lethality should rise everywhere at more or less the same rate, too. This, too, is consistent with what we see in Newark.

On the other hand, preemption effects work only within a social or business network. If I have no connection with you, I don't gain from killing you and I don't fear you will kill me. Disputes presume some engagement. Thus the preemption model is consistent with the rise in murder and lethality being confined to a single demographic group, African-American men.

Many other stories about the rise in homicide are not consistent with these facts. For instance, if homicide rose because a particular type of weapon became cheaper or more easily available or better, we would not see an increase in lethality in all dimensions, but we would see a rise across all demographic groups. Worse emergency medicine would also be seen as a rise in murder across all demographic groups.

## 6.2 Arrest Rates

The ratio of arrests for murder to murders has declined precipitously in Essex County, falling from 0.811 in 1998 to 0.462 in 2005. Arrests per murder is a crude indicator for the clearance rate, since several individuals are sometimes arrested for one murder, since one individual may be arrested

for several murders, and since arrests may not occur during the same year in which a murder is recorded. But it is the most widely available measure. Nationally, the ratio is currently close to one.

Table 7 shows how the arrest/murder ratio declined in Essex County while remained fairly stable in the rest of New Jersey, in the aggregate. There were actually fewer murder arrests in Essex County in 2005 than in 1999.

Table 7: Arrest/Murder Ratio: Essex County and Rest of State, 1998-2005

	Essex County	Rest of State
1998	0.811	0.847
1999	0.738	0.933
2000	0.602	0.908
2001	0.592	0.866
2002	0.477	0.872
2003	0.652	0.879
2004	0.463	0.816
2005	0.426	0.801

Source: New Jersey State Police.

What does this fall in arrest rates tell us about changes in murder? From 2000 to 2005, the Essex arrest rate fell 23%. If we use Corman and Mocan's  $-0.4$  elasticity, the implication is 9% increase in murders. If we think of the deterrent effect of an arrest as acting with a one-year lag, then the relevant comparison is between 1999 and 2004: a 37% decrease in the arrest rate, which implies a 15% murder rise. DRS (2003) use linear specifications, not logarithmic. Their results imply 2-5 more murders using the contemporaneous approach, 3-7 more using the lagged approach. The tops of these ranges are close to the respective Corman-Mocan implications.

These falling arrest rates may have been exacerbated by falling conviction rates. The Essex prosecutor's office during this period developed a flagrant reputation for failing to win convictions in homicide cases (Kleinknecht and Schuppe 2006). If the conviction rate were falling after 2000, then it would probably have contributed to the rise in murder. But we do not know whether it was rising or falling. Moreover, econometric studies of conviction rates (as opposed to arrest rates) are rare.

### 6.3 Prisoners

The number of state prisoners who were originally sentenced from Essex County fell 29.4% from January 1999 to January 2006, 15.4% from January 2001 to January 2006. Table 8 provides details.

Table 8: New Jersey State Prison Population by County, 1994-2006, Selected Years (Number of prisoners sentenced from selected counties; population in early January.)

	Essex	Hudson	Union	Passaic	Mercer	Camden
1994	4515					
1996	5426					
1997	5518					
1998	5643					
1999	6241					
2001	5209	2695	2327	2218	1197	3874
2003	4830	2455	2211	2179	1275	3477
2004	4789	2518	2268	2264	1395	3457
2005	4607	2388	2176	2204	1390	3404
2006	4408	2269	2238	2294	1345	3580
Change 1999-2006	-29.4%					
Change 2001-2006	-15.4%	-15.8%	-3.8%	+3.4%	+12.4%	-7.6%

Source: New Jersey Department of Corrections; website and personal communication.

As we saw in the last section, studies differ widely on the effect of prisoners on murder. Some studies find no effect, and Corman-Mocan's  $-0.08$  elasticity implies only a 1.2% rise in murders. But the results of Devine et al. (1988) and Marvell and Moody (1997) imply roughly a 20% murder increase in Essex County from 2000 to 2005. The results of Raphael and Stoll (2004) are consistent with those of Marvell and Moody, and in fact imply a slightly larger increase in murder.

### 6.4 Police

According to the FBI Uniform Crime Reports, the number of police officers in Newark fell by 6.0% from October 31, 2000 to October 31, 2005. (Counting police officers is not an exact science, but this is the data source that Levitt used.) Levitt's (2002) results imply that this fall in police

strength should have raised murders in Newark by 5.4%. However, several extenuating factors imply that policing in Newark may have contributed more to the rise in murders than Levitt's average indicates. During this period the physical facilities of the NPD fell into severe disrepair and the command structure went through several upheavals.

## 6.5 Accounting for the Increase in Murder

Taking upper bounds of these three ranges implies a predicted 45% rise in murders from 2000 to 2005; that is, an increase from 59 to 86. Actual murders in 2005 were 98. The difference of 12 is not statistically significant.<sup>10</sup> We might be tempted to say that these three changes—fewer arrests, fewer prisoners, fewer police—account for the whole rise in murders. Such a conclusion would be strained, however. The bottom of the ranges predict only about 67 murders in 2005, not 86. The Marvell and Moody paper on prison population is much weaker than the Levitt paper on the usual criteria. And the three changes are not necessarily independent so that using them to compound each other is questionable. Instead, we interpret the upper bound accounting exercise as a demonstration that in combination with these three factors the amount of non-linearity prediction bias does not need to be unreasonably large to account for most of the rise in murder. These three factors and a modest amount of strategic complementarity do a pretty good job of explaining what happened in Newark.

## 6.6 Interjurisdictional Spillovers

Could interjurisdictional spillovers have contributed to the rise in murder? Municipalities in New Jersey are geographically small, and people cross town lines often for business and pleasure. Disputes that start in one town are frequently settled in another. Irvington murderers may hunt their victims in East Orange. This causes murders in East Orange, and it also makes East Orange residents invest in greater lethality, so that intra-East Orange disputes are more likely to result in murder. Changes in fundamentals in one town can raise or lower murder in adjacent towns.

Table 9 shows that fundamentals deteriorated substantially in several municipalities adjacent to Newark, especially Jersey City. But since the rate of deterioration of fundamentals in these towns

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<sup>10</sup>The methods developed by Fisz (1955) and Detre and White (1970) indicate that the analog of a t-statistic for the null hypothesis that Poisson variables of 86 and 98 are drawn from the same distribution is slightly less than 0.90. Murders in Newark, however, are a stuttering Poisson process because sometimes multiple murder incidents occur. Considering 86 and 98 as stuttering Poisson variables would reduce the t-statistic further.

was not much different from the rate in Newark, they probably did not generate net interjurisdictional spillovers in one direction or the other.

Table 9: Percent Changes in New Jersey Cities, 2000-2005

Cities adjacent to Newark					
	Murder	Arrest Rate	Prisoners	Police	Implied Murder Change
Jersey City	+111	-49.1	-15.8	-3.8	+49
Elizabeth	+42	-41.5	-3.8	-3.7	+26
East Orange	+17	-37	-15.4	-7.5	+47
Irvington	+133	-37	-15.4	+14.8	+36
Other cities with many murders					
Paterson	+18	-14.2	+3.4	+3.3	-2
Trenton	+121	-38.0	+12.4	-0.3	-3
Camden	+42	-26.1	-7.6	+3.2	+18
Elasticity		-0.4	-1.3	-0.9	

Table 9 also can help answer the question of why murders rose in most other New Jersey cities. We perform essentially the same calculation we did for Newark with upper-bound elasticity estimates. Since these cities have only between 10 and 38 murders a year, comparing only two years introduces a huge amount of noise. The main message from the table is that a great deal of the change in North Jersey murders can be explained by the three fundamentals of arrests, prisoners, and police. These worsened everywhere but Paterson, and murders rose substantially everywhere but Paterson. (Trenton appears to be an anomaly in this table. 2005 was a very bad year for Trenton, and noise may be the best story available. Murders in Trenton went from 18 in 2004 to 31 in 2005 and back to 18 in 2006. This difference is significant at the 10% level. Trenton had three homicides in the first third of 2007, according to the Trenton Police Department April Uniform Crime Report.)

## 6.7 Witness Intimidation

Witness intimidation is a major problem in Newark that contributes to the low arrest and conviction rates. It also contributes to murder directly, since some murders are committed to keep witnesses

from testifying. However, there are no measures of witness intimidation, and so it is impossible to tell whether it was increasing or decreasing during the period we are studying.

Witness intimidation, like preemption, is an instance of strategic complementarity. In a world with little crime and little witness intimidation, I know that you will be severely punished if you try to keep me from testifying against you, and so I can testify against you with impunity. This confidence is based on my belief that other witnesses will step forward to testify against you if you harm me. If I lose confidence in future witnesses, then I have more reason to fear you and I may not testify myself either. Intimidated witnesses beget intimidated witnesses. Reductions in criminal justice effectiveness get magnified: when a police department loses a few detectives, for instance, the most timorous witnesses become intimidated, but knowing that the most timorous witnesses won't testify makes slightly less reticent witnesses reticent, too.

A rigorous model of witness intimidation, then, would endogenize arrest and conviction rates. Such a model is beyond the scope of this paper, but is a worthy subject for future research.

## 6.8 Drugs

Many murderers and murder victims are or were engaged in the illicit drug business, either as buyers or sellers or both. The reasons for this association between drugs and murder are well-known: legal means of dispute resolution are not available to this business; markets are imperfect and so deaths of particular individuals can present large and persistent profit opportunities for other individuals; cooperation with law enforcement can be very harmful to an enterprise and so assassination of those who cooperate can be very profitable; and the marginal penalty for murder is small for many people in this business (the prospect of a life sentence for murder is less intimidating for a person who stands a very good chance of soon being sentenced to 20 years as a drug dealer than it is for someone who has committed no other crimes.) Selection may also play a role, as naturally vicious people may have a comparative advantage in this industry.

Table 10: Prevalence Estimates of Drug Use in New Jersey, 1999-2004, Percent of population 12 and over

	1999	1999-2000	2000-01	2002-03	2003-04
Past Month Illicit Drug Use	7.2	6.1	5.8	7.0	6.9
Past Year Cocaine use	2.1	1.5	1.3	2.2	2.0

Source: SAMHSA, National Household Survey of Drug Abuse.

But nothing indicates that changes in illicit drug markets played a major role in the rise in murder in Newark. Generally, two sorts of changes could increase murders. First, an outward shift of the demand curve could increase the quantity of drugs sold, and so raise the number of people involved in the industry. Tables 10-11 show no rise in the consumption of illicit drugs, at least up until the middle of the period. (More recent information is unavailable.)

Table 11: Emergency Room Mentions of Heroin and Cocaine, Newark Metropolitan Area, 1998-2002

	Heroin	Cocaine
Jan-June 1998	2575	1481
July-Dec. 1998	2437	1349
Jan-June 1999	2301	1180
July-Dec. 1999	2433	1137
Jan.-June 2000	2285	1080
July-Dec. 2000	2114	1043
Jan.-June 2001	1849	1031
July-Dec. 2001	1869	384
Jan.-June 2002	1938	1023
July-Dec. 2002	1793	378

Source: SAMHSA, Drug Abuse Warning Network.

Second, an increase in the difference between retail and wholesale prices would reflect a larger sum of money being allocated to industry employment and to ex post profits. More money would be involved in distributing the same quantity of drugs, and that money could give rise to more murders. Becker, Murphy and Grossman (2006) argue that greater enforcement efforts increase this difference and Miron (1999, 2001) shows that enforcement efforts Granger-cause murders in a long U.S. time series and in a cross-section of nations. Table 12 shows estimated prices for major illicit drugs in New Jersey between 2000 and 2006. In North Jersey, the wholesale-retail mark-up fell on average. This should have reduced murders. The wholesale-retail mark-up rose in South Jersey; this may be why murders rose in Camden more than the changes in arrests, prisoners, and police predicted.

Table 12: Drug Prices in New Jersey, First Quarter of Calendar Year, 2000-2006

North Jersey						
	Heroin		Cocaine		Crack	
	Kilo	Bag	Kilo	Bag	Kilo	Bag
2000	79	17	37	12	25	16
2001	71	10	26	10	23	14
2002	85	14	27	12	31	22
2003	63	11	25	14	24	22
2004	72	12	23	14	39	12
2005	67	9	25	14	26	14
2006	54	9	19	14	24	14
% change	-32	-47	-49	+17	-4	-12
South Jersey						
2000	158	16	29	24	23	10
2001	177	15	27	22	25	16
2002	177	16	29	16	19	7
2003	98	16	27	24	19	10
2004	98	17	28	16	19	10
2005	98	22	25	22	19	14
2006	88	22	22	22	25	14
% change	-44	+37	-224	-8	+9	+40

Point estimates calculated as geometric means of upper and lower limits of bounds given in the original data. Kilogram prices are in thousands of dollars.

Source: Drug Enforcement Administration, Illicit Drug Price Reports.

The ethnic pattern of the rise in murders in Newark provides weak corroboration for the assertion that drugs did not play a major role in the increase in murders. National data indicate that non-Hispanic blacks, non-Hispanic whites and Hispanics consume illicit drugs at roughly comparable rates, and Hispanics and blacks are both incarcerated at high rates for drug crimes.<sup>11</sup> Thus changes

<sup>11</sup>At year-end 2005, 23.7% of black prisoners and 22.9% of Hispanic prisoners under state jurisdiction were charged with drug crimes. But overall the rate of per capita imprisonment among Hispanics was around two-fifths of the rate among blacks (Harrison and Beck 2007).

in the drug business should have increased murders of Hispanics and possibly of whites in Newark, not just blacks. As we have seen, that did not happen.

## 6.9 Guns

Although gun homicides accounted for most of the increase in Newark murders, changes in the price and availability of guns probably did not make a major contribution to the murder rise. More guns and more lethal guns came to Newark because people wanted them and were willing to pay more for them, not because they were cheaper or easier to obtain.

Two strands of argument support this conclusion. First, national trends are different from Newark trends. Although murders by gunshot have been rising in Newark since 2000, they have not been rising nationally. The national peak in gunshot murders was 1993, and the decline to 2004 was over 40%. Since the wholesale gun market is national, this trend casts some doubt on a simple story about lower gun prices being responsible for more gunshot murders in Newark. Indeed, since the rise in gross gunshot discharge incidents is a relatively small part of the story of rising gunshot murders in Newark, the only way gun prices could have had a major impact would be for the price of high-quality guns to fall relative to the price of low-quality guns. But if that were to be happening on the wholesale level, other cities would experience the same rise in deadliness that Newark has experienced, and national gunshot murders would increase.

Second, suicide data do not indicate greater availability of either all guns or better guns in New Jersey. Some researchers have used the proportion of suicides that occur by gunshot as an indicator of the how available guns are in an area (see, for example, Cook and Ludwig 2006). The logic is the following: If guns are easy to acquire, then almost everybody attempting suicide will use a gun. If guns are hard to acquire, then almost nobody attempting suicide will use a gun. So if we observe that a high proportion of suicides are by gun, we can conclude that guns are easy to obtain, and vice versa. Similarly, if we observe a rising proportion of suicides by gun, we can conclude that guns are easier to obtain.

Table 13 provides information on suicides in New Jersey. There is no evidence of an upward trend, although the numbers involved are small. Since the data report on *successful* suicides, a rise in the *quality* of guns, holding everything else equal, would increase the proportion of gunshot suicides. This table is weak evidence against the hypothesis that easier gun availability is driving the rise in gun murders. If guns were easier to obtain, we would expect to see them used more often for suicides as well as for homicides.

Table 13: Proportion of Suicides by Firearm in New Jersey, 1993-2003

	% of Total	% of African-American	% of African-American Male
1993	36		
1994	32		
1995	34		
1996	30		
1997	34		
1998	37	40	43
1999	35	48	51
2000	28	19	22
2001	28	41	46
2002	32	42	44
2003	31	28	37

Source: New Jersey Department of Health and Senior Services.

On the other hand, in 1998, New Jersey became the first and for most of this period the only state to segregate gang members in a particular prison, East Jersey State. Cook et al. (2005) show that personal networks are crucial to the operation of illegal gun markets. Prison segregation may have improved networks among New Jersey gang members, making it easier for them to obtain high quality guns. This would explain why New Jersey cities (except Paterson) are so different from almost all cities in the rest of the nation. But this argument is entirely speculative.

## 6.10 Unemployment

Between 2000 and 2006, unemployment rose in Newark and then fell back almost to its original level. According to the New Jersey Department of Labor and Workforce Development, the Newark unemployment rate rose modestly over the period, from 8.0% in 2000, to 8.5% in 2005 and 8.3% in 2006, although it was much higher in some of the intervening years.

Raphael and Winter-Ebmer (2001) is probably the most rigorous study of unemployment effects on crime. They find significant positive effects for most crime: most crimes go up when unemployment goes up. But for murder they find negative effects, which are significant in several specifications with instrumental variables. Cook and Zarkin (1985) also find that murder is procyclical.

Hence the business cycle did not contribute to the rise in murder in Newark, and may even have reduced it.

## 7 Policies to Reduce Murder

No matter why murders rose, making them fall is a worthwhile goal. In this section we will examine three programs for murder-reduction for which claims of efficacy have been made, evaluate them in light of both the empirical literature and our model, and finally make some recommendations about how to reduce murders in Newark.

### 7.1 Programs That May Have Worked

Three murder-reduction programs in the last 15 years have received considerable attention: Operation Ceasefire in Boston, Project Exile in Richmond, VA, and the combination of Compstat and broken windows in New York City. Murders fell substantially while all of these programs were in operation, but nobody knows what would have happened if the programs were not in operation. None of these programs has been subjected to a high quality test like a controlled experiment or a large natural experiment with an independent instrumental variable. Therefore serious questions have been raised about whether each of these programs actually *caused* the reduction associated with it, and these objections are essentially unanswerable. There just is not enough independent variation. Rosenfeld et al. (2005) is a good summary of these programs.

Directed at youth, Operation Ceasefire in Boston involved direct communication with gang members that violence would not be tolerated. Police, youth workers, parole and probation officials, the US attorney, and the local district attorney all told gang members in a series of meetings, “We’re here because of the shooting. We’re not going to leave until it stops. And until it does, nobody is going to so much as jaywalk, nor make any money, nor have any fun” (Kennedy et al., 2001: 27-28). Posters described what happened to recalcitrant gang members: “They were warned. They didn’t listen.” The idea was to turn gang pressure into pressure against shooting. Simultaneous efforts were made to trace and interdict crime guns.

Richmond’s Project Exile was directed at older offenders, not youth, but also employed an extensive communications strategy. Exile primarily involved sentence enhancements for violent or drug crimes involving guns. The method was federal prosecution, because federal crimes carry longer sentences and higher bail, and federal prisons are out of state. These harsh sentences

were announced with a media blitz: “An illegal gun will get you five years in federal prison,” the billboards and ads said.

New York’s strategy was two-pronged, and it is difficult to sort out their independent effects. One prong was strict accountability for police officers through Compstat, and the other was a crackdown on misdemeanors—the “broken windows” strategy named after Wilson and Kelling’s (1982) famous article. There was no explicit public relations strategy, but the initiatives received enormous media coverage. The message was that police were getting tough, and the flood of misdemeanor arrests was in part meant to demonstrate to potential offenders that that was in fact the truth.

Thus a public message was part of all three programs. That the message was public is crucial for our model. To change his behavior substantially, an agent needs to know not only that his payoffs have changed, but also that the payoffs of the agents he interacts with have changed too. All three programs tried to accomplish both tasks.

All three programs also tried to punish both shootings and murders. This strategy was not explicitly part of our model, since all that mattered was the expected net cost of given lethality. But since shootings are much more common than murders, certainty may have more deterrent value than severity, and actual punishments are probably needed for credibility, the strategy seems reasonable.

We have already noted that all three programs have received both favorable and unfavorable evaluations, but our model suggests that the unfavorable evaluations of Ceasefire and Exile may be too harsh because of narrow-estimation bias. The consensus among peer-reviewed papers is that broken-windows did not reduce murders, but the evidence is inconclusive on Compstat.

In Braga et al. (2001), Kennedy et al. (2001), and Piehl et al. (2003), the Ceasefire research team looked at the time series of youth gun homicides, youth gun assaults, and shots fired calls in Boston. They found reductions in youth violence in the Boston time series, controlling for a number of trends, including adult homicides, and in comparison with 29 other New England cities and 39 large U.S. cities. Since youth homicides may have influenced adult homicides, at least some of these tests were too strict, but Ceasefire passed them.

Rosenfeld et al. (2005), however, used a national data set of 95 large cities and controlled for a wide array of demographic and criminal justice variables, including police strength and incarceration, and found that the Boston decrease in youth gun homicide was not statistically significantly different from the sample average when the age group 15-24 was used. With the age group 11-24,

the decrease was marginally significant. They note (p. 434): “The lack of statistical significance reflects Boston’s low youth firearm homicide counts during the intervention period (from 21 in 1996 to 10 in 1999).” Narrow-estimation bias may contribute to the problems of small numbers. Cook and Ludwig (2006) also raise questions about the power of the Ceasefire evaluations.

In contrast, Rosenfeld et al. find a statistically significant decrease in gun homicides when they apply their methods to Project Exile, even though their point estimate of Ceasefire’s effect was larger. Richmond had more homicides to work with. Raphael and Ludwig (2003), however, reached the opposite conclusion about Exile.

There are several differences between the two papers, most especially a controversy about how to treat the unusually large number of gun homicides in 1997, the year the intervention began but before much happened. More notable for us is that Raphael and Ludwig control for juvenile homicides in Richmond when they look at adult homicides in Richmond. We don’t know what the effect of using this control is, but it is another example of possible narrow-estimation bias.

Raphael and Ludwig also argue that the reduction in murders in Richmond was mostly mean-reversion. Our model lets us interpret this argument and the data they present for it quite differently. They show that across cities the change in the natural log of gun homicide rates in the late 1990s, when rates were falling, was negatively correlated with the change between the mid-1990s and the mid-1980s. Cities that had bigger increases in the early decade had bigger decreases in the later quinquennium. Since Richmond had a large increase, mean reversion implies that it should have a big decrease, too. However, general evidence for mean-reversion in homicide rates is scant. Corman and Mocan check for it in New York City monthly data in both of their papers, and cannot reject unit roots. The national murder rate time series over the past 30 years is clearly not mean-reverting.

Our model suggests an alternative interpretation for the correlation Raphael and Ludwig find. Suppose fundamentals change roughly the same way everywhere. Then war zones will have bigger increases in murder than peaceable kingdoms when fundamentals are getting worse, and bigger decreases when fundamentals are getting better. If we compare a period when fundamentals are getting better everywhere with a period when fundamentals are getting worse everywhere, the Raphael-Ludwig correlation will hold, even if murder rates are not a mean-reverting process. Thus the Raphael-Ludwig correlation provides some weak confirmation for our model of murder.

This way of looking at murder rates also suggests another way of interpreting the conclusion from Rosenfeld et al. that Project Exile reduced murder rates significantly while Operation Ceasefire

and the New York combination did not. Richmond had a much higher murder rate than either New York or Boston at the start of the interventions. Thus the same intervention would have produced a bigger effect in Richmond than in the other two cities. Rosenfeld et al. may have found not that Project Exile was more effective, but that Richmond was more receptive.

For New York, some papers test broken-windows alone and some test the combination of broken-windows and Compstat; no work tests Compstat alone. In their study using monthly data from New York City police precincts, Corman and Mocan (2005) include citywide misdemeanor arrests as an explanatory variable. Misdemeanor arrests have no significant effect on murder, although they did reduce robbery and motor vehicle theft. Kelling and Sousa (2001) also studied New York City, but only for approximately a decade. They found that violent crime declined more in precincts that had more misdemeanor arrests over the decade, but they did not publish any results about homicide. They also do not control for own arrests or police strength, and do not address reverse causation (less violent crime would allow police more time to make misdemeanor arrests). Harcourt and Ludwig (2006) show that neither of these studies could support a finding that misdemeanor arrests reduce crime (they use the Kelling-Sousa and Corman-Mocan approaches on misdemeanor arrests to demonstrate that success of the New York Yankees drives crime in New York)—although in fact neither study found that such arrests reduce murder.

The multi-city study of Rosenfeld et al. tested broken windows and Compstat jointly by comparing New York’s homicide rate decline with the national average, both adjusted for controls. They found that, adjusted for controls, New York’s homicide decline was not bigger than the national average (the point estimate was that it was smaller, but insignificantly so).

Thus while there are some indications that programs that involve public communications and concentrate on shooters as well as killers may have some efficacy, the evidence is not compelling for any particular program. (This is essentially the same conclusion that Levitt (2004) reaches in his review of the 1990s crime decline, and that Cook and Ludwig (2006) reach in their review of gun violence.) Of course, the evidence for such traditional variables as arrest rates and police strength is fairly strong.

## **7.2 Implications for Newark**

What do these results imply about policies for Newark to pursue? The most obvious implication is that making more arrests for murder and convicting more guilty suspects should be high priorities for the Newark Police Department and the Essex County Prosecutor’s office. More resources devoted

to these tasks probably have two multiplier effects: more arrests and more convictions make more witnesses come forward, and more witnesses lead to even more arrests and more convictions; more arrests and more convictions lead to fewer people willing to murder for gain; fewer people willing to murder for gain lead to fewer people killing for self-protection. Shooters should probably be included with murderers in this high priority effort.

Expansions of the police department to accomplish this end probably pass cost-benefit tests. Levitt's (2002) elasticity of murder with respect to police strength implies that added police expenditures in general reduce murders at a cost of about \$2 million per life in Newark, well below the value of most American statistical lives, though not above the value that Levitt and Venkatesh (2000) conclude that young gang members place on their lives. Expansions concentrated on homicide reduction should do much better, as we have argued in the literature review.

The second obvious implication is that public messages should not be designed to tell people that they might be shot. Billboards that say, "Stop the killing" tell rational people that a lot of killing is going on and they need to protect themselves; so do repeated assertions that murders are going up everywhere (which is not true). Repeated laments that witnesses never testify tell rational would-be witnesses that testifying is very dangerous.

Of course, public messages cannot be wrong or misleading either; one cannot tell people that drinking Newark water makes bullets bounce off them. Instead, the message should be a credible one that more apprehensions are being made, or more witnesses are coming forward, or more old cases are being solved. (It might also be worthwhile to publicize how abysmally inaccurate most Newark shooters are.) For this to work, of course, actual progress has to be made on the necessary detective work and witness protection.

Raising the cost of holding high quality guns reduces murders with all types of guns, and so can have a substantial payoff. How to do this is less obvious. Cook and Ludwig (2006) provide a useful summary of the empirical literature on gun control strategies. They find that directed patrolling against illicit carrying stands the best chance of reducing homicide.

Raising the marginal penalty for murder by reducing penalties for other crimes is a riskier strategy, but worth exploring. Shifting police and prosecutorial resources from other crimes accomplishes this implicitly, since the marginal penalty for murder depends on the expected punishment for having committed other crimes. But in doing so it is important that resources be shifted from those crimes that people contemplating murder are likely to have committed, or are likely to commit soon.

Prisoner re-entry programs also implicitly reduce penalties for non-murder crimes and so raise the marginal penalty for murder. If your life is ruined for any crime you commit, then if you have committed any other crime, the marginal penalty for murder is small. (A rigorous statement of this proposition is in O’Flaherty, 1998.) Making post-prison life better for other crimes makes murder more costly. But this is a long-run effect that may not be of any relevance in the next few years.

Programs that focus on former prisoners have a second possible payoff. For reducing murder, the most crucial place to lower the probability density function of  $\gamma$  is probably slightly above 0—people who would not kill if self-protection were not an issue, but who do so readily when self-protection is an issue. In a different atmosphere or with a different crowd, they would not kill, but their willingness to kill in the dangerous environment they find themselves in encourages still more people to arm themselves and kill preemptively. If the probability density in neighborhood were to be decreased and moved to slightly higher values of  $\gamma$ , equilibrium murder would fall considerably. Former prisoners are probably heavily concentrated in this crucial range of  $\gamma$ .

How to change  $\gamma$  for this group is not certain, however. Employment is likely to help, since it will occupy their time and further many of their aspirations. But in general and in the aggregate, there is scant evidence that employment reduces murder as Raphael and Winter-Ebmer (2001) and Cook and Zarkin (1985) have shown.

Recreation, broadly conceived, may be more strategic, considering the large number of disputes among Newark’s murder motives. The key is finding things that 30-year-old former prisoners like to do after work, and helping them to do these things in an atmosphere without guns and where disputes are settled amicably, or with fists. Churches may assist with this, but some effective forms of recreation may not be wholesome enough for churches or even the city to sponsor directly.

Recreational segregation may also reduce murder. Consider a society where the equilibrium number of murders is far above the number of autonomous murders (our picture of Newark today). To make the situation simple, assume  $\beta = \alpha$ , and so  $F(0)$  is the number of autonomous murder attempts. Now split the society in two, with all agents with negative  $\gamma$  in one new society, and all those with positive  $\gamma$  in the other new society. Aggregate murder goes down to the autonomous level: the positive- $\gamma$  society is murder-free, while in the negative- $\gamma$  society everyone shoots everyone else—but all of these people were shooting in the original society anyway—and they would be the only people shooting in the original society at the autonomous murder rate. (In the long run segregation may even be better, since the negative- $\gamma$  society will steadily lose population from murder and incarceration, but the population of the positive- $\gamma$  society will stay the same.)

The city should therefore encourage recreational segregation. One way might be to establish different categories of bars, and allow some categories greater privileges like later closing hours in return for restrictions like a no-guns policy. Privileges would be lost if a bar were connected to too many shootings.

On the other hand, closing down the bloodiest bars is a bad policy, because it promotes the wrong kind of recreational integration. Murderers are going to go someplace, and it is better that they be with themselves than that they be forced to associate with people who will as a result become killers in self-protection.

## 8 Conclusion

We have no direct empirical evidence about our primary theoretical contribution—the difference between autonomous and equilibrium murder that arises because of self-protective preemption—although results like those of Raphael and Ludwig (2003) can be interpreted as supportive. Clearly much good empirical work can and should be done in this area. A lot of theoretical work is missing, too—detailed models of segregation and models of witness intimidation have already been cited. In the meanwhile, we have good circumstantial evidence that strategic complementarity is a big part of the explanation for why murder rose in Newark and in other cities in North Jersey.

Substantively, murders can be reduced in Newark. Murders rose because small changes in fundamentals were magnified by a cycle of self-protective preemption (and probably also by a cycle of self-protective witness temerity). Some irreversible investments were made, but the changes in fundamentals needed to reverse the process, while larger than those that started the process, are probably not prohibitively large.

## Appendix

### Proofs

**Proof of Proposition 1.** Given any beliefs  $(\lambda, \mu)$ , an individual's likelihood of being shot if he chooses to remain unarmed is  $\lambda\alpha + \mu\beta$  and the expected payoff from choosing lethality 0 is therefore

$$\pi_0 = -\delta(\lambda\alpha + \mu\beta).$$

The payoff from shooting with lethality  $\alpha$  is

$$\pi_\alpha(\gamma) = -(1 - \lambda - \mu)\gamma\alpha - \lambda p(\alpha, \alpha)(\gamma + \delta) - \mu(p(\alpha, \beta)\delta + p(\beta, \alpha)\gamma).$$

Similarly the payoff from shooting with lethality  $\beta$  is

$$\pi_\beta(\gamma) = -(1 - \lambda - \mu)\gamma\beta - \lambda(p(\beta, \alpha)\delta + p(\alpha, \beta)\gamma) - \mu p(\beta, \beta)(\gamma + \delta).$$

Define

$$u_{xy} = p(x, y) - p(x, x) \tag{5}$$

$$v_{xy} = p(x, y) - p(y, y) \tag{6}$$

Note that  $u_{\alpha\beta} > 0 > u_{\beta\alpha}$  and  $v_{\alpha\beta} > 0 > v_{\beta\alpha}$  and

$$\pi_\beta(\gamma) - \pi_\alpha(\gamma) = -(1 - \lambda - \mu)\gamma(\beta - \alpha) - \gamma(\lambda u_{\alpha\beta} - \mu u_{\beta\alpha}) - \delta(\lambda v_{\beta\alpha} - \mu v_{\alpha\beta}).$$

Hence  $\pi_\beta(\gamma) - \pi_\alpha(\gamma)$  is strictly decreasing in  $\gamma$ . Define

$$\gamma_1 = \frac{\delta(\mu v_{\alpha\beta} - \lambda v_{\beta\alpha}) - c}{(1 - \lambda - \mu)(\beta - \alpha) + \lambda u_{\alpha\beta} - \mu u_{\beta\alpha}}. \tag{7}$$

Then

$$\pi_\beta(\gamma_1) - \pi_\alpha(\gamma_1) = c.$$

Now consider

$$\begin{aligned} \pi_\alpha(\gamma) - \pi_0(\gamma) &= -(1 - \lambda - \mu)\gamma\alpha - \lambda p(\alpha, \alpha)(\gamma + \delta) - \mu(p(\alpha, \beta)\delta + p(\beta, \alpha)\gamma) + \delta(\lambda\alpha + \mu\beta) \\ &= -(1 - \lambda - \mu)\gamma\alpha - \gamma(\lambda p(\alpha, \alpha) + \mu p(\beta, \alpha)) + \delta(\lambda(\alpha - p(\alpha, \alpha)) + \mu(\beta - p(\alpha, \beta))). \end{aligned}$$

Hence  $\pi_\alpha(\gamma) - \pi_0(\gamma)$  is strictly decreasing in  $\gamma$ . Define

$$\gamma_2 = \frac{\delta(\lambda(\alpha - p(\alpha, \alpha)) + \mu(\beta - p(\alpha, \beta)))}{(1 - \lambda - \mu)\alpha + \lambda p(\alpha, \alpha) + \mu p(\beta, \alpha)}. \tag{8}$$

Then

$$\pi_\alpha(\gamma_2) - \pi_0(\gamma_2) = 0.$$

Since  $\gamma_1$  is decreasing in  $c$  and  $\gamma_2$  is independent of  $c$ , there exists  $\tilde{c} \geq 0$  such that  $\gamma_1 < \gamma_2$ . In this case, the following holds: (i) for  $\gamma < \gamma_1$ ,  $\pi_\beta(\gamma) - c > \pi_\alpha(\gamma) > \pi_0(\gamma)$ , (ii) for  $\gamma > \gamma_2$ ,  $\pi_\beta(\gamma) - c < \pi_\alpha(\gamma) < \pi_0(\gamma)$ , and (iii) for  $\gamma \in (\gamma_1, \gamma_2)$ ,  $\pi_\alpha(\gamma) > \max\{\pi_0(\gamma), \pi_\beta(\gamma) - c\}$ . Since the best response to any beliefs  $(\lambda, \mu)$  has this structure, this must also be the case for the best response to equilibrium beliefs.

To prove that a symmetric Bayes-Nash equilibrium exists, consider any arbitrary beliefs  $(\lambda, \mu)$  and let  $\gamma_1(\lambda, \mu)$  and  $\gamma_2(\lambda, \mu)$  denote the best response thresholds as defined above. Define  $G : [0, 1]^2 \rightarrow [0, 1]^2$  as follows

$$\begin{aligned} G_1(\lambda, \mu) &= F(\gamma_2(\lambda, \mu)) - F(\gamma_1(\lambda, \mu)) \\ G_2(\lambda, \mu) &= F(\gamma_1(\lambda, \mu)) \end{aligned}$$

Since  $G$  is continuous and  $[0, 1]^2$  is compact, there exists  $(\lambda^*, \mu^*)$  such that

$$(\lambda^*, \mu^*) = G(\lambda^*, \mu^*)$$

from Brouwer's Fixed Point Theorem. By definition of  $\gamma_1$  and  $\gamma_2$ , the following strategy  $s^*(\gamma)$  is an equilibrium:  $s^*(\gamma) = \beta$  for  $\gamma < \gamma_1(\lambda^*, \mu^*)$ ,  $s^*(\gamma) = \alpha$  for  $\gamma \in (\gamma_1(\lambda^*, \mu^*), \gamma_2(\lambda^*, \mu^*))$ , and  $s^*(\gamma) = 0$  for  $\gamma > \gamma_2(\lambda^*, \mu^*)$ . ■

**Proof of Proposition 2.** Using (5-6) together (1), we obtain

$$\begin{aligned} u_{xy} &= p(x, y) - p(x, x) = \frac{1}{2}(2-x)(y-x) \\ v_{xy} &= p(x, y) - p(y, y) = \frac{1}{2}y(y-x) \end{aligned}$$

This, combined with (7), yields (after simplification) the following expression for the cost threshold below which lethality  $\beta$  is chosen

$$\gamma_1 = \frac{\delta\omega - 2c'}{2 - \omega}, \tag{9}$$

where  $c' = c/(\beta - \alpha)$ . Similarly, using (7) and (1), we get

$$\gamma_2 = \frac{\delta\omega}{2 - \omega},$$

so  $\gamma_1 < \gamma_2$  for all values of  $c > 0$ .

Given that players are ex ante identical and at most one is killed in any interaction, the likelihood of a murder is simply twice the likelihood that a given player (player 1, say) is killed. Hence the likelihood of a murder is

$$\begin{aligned}
& 2[(1 - \lambda - \mu)\omega + \lambda(\lambda p(\alpha, \alpha) + \mu p(\alpha, \beta)) + \mu(\lambda p(\beta, \alpha) + \mu p(\beta, \beta))] \\
= & 2(1 - \lambda - \mu)\omega + \lambda(\lambda\alpha(2 - \alpha) + \mu\beta(2 - \alpha)) + \mu(\lambda\alpha(2 - \beta) + \mu\beta(2 - \beta)) \\
= & 2(1 - \lambda - \mu)\omega + \lambda(2 - \alpha)\omega + \mu(2 - \beta)\omega = \omega(2 - \omega).
\end{aligned}$$

Next consider the expected number of gun discharges per incident. The likelihood of two discharges is

$$(\lambda(1 - \alpha) + \mu(1 - \beta))(\lambda + \mu) = (\lambda + \mu - \omega)(\lambda + \mu).$$

The likelihood of exactly one discharge is

$$\begin{aligned}
& (1 - \lambda - \mu)(\lambda + \mu) + \omega + (\lambda(1 - \alpha) + \mu(1 - \beta))(1 - \lambda - \mu) \\
= & (1 - \lambda - \mu)(2(\lambda + \mu) - \omega) + \omega.
\end{aligned}$$

Hence the expected number of gun discharges per incident is

$$2(\lambda + \mu - \omega)(\lambda + \mu) + (1 - \lambda - \mu)(2(\lambda + \mu) - \omega) + \omega = (\lambda + \mu)(2 - \omega)$$

as claimed. ■

**Proof of Proposition 3.** Consider any equilibrium  $(\lambda^*, \mu^*)$ . Using the notation in the proof of proposition 1, we have

$$G(0, 0) = (F(0) - F(-c'), F(-c')) \neq (0, 0).$$

Since only fixed points of  $G$  are equilibria,  $(\lambda^*, \mu^*) \neq (0, 0)$ . Since both  $\lambda^*$  and  $\mu^*$  are nonnegative by definition, either  $\lambda^*$  or  $\mu^*$  (or both) must be positive. Recall that  $p$  is decreasing in its first argument and  $p(0, y) = y$  by definition, so  $p(\alpha, \alpha) < p(0, \alpha) = \alpha$  and  $p(\alpha, \beta) < p(0, \beta) = \beta$ . This, together with the fact that either  $\lambda^*$  or  $\mu^*$  must be positive, implies from (8) that  $\gamma_2^* > 0$ . Hence

$$\lambda^* + \mu^* = F(\gamma_2^*) > F(0) = \tilde{\lambda} + \tilde{\mu} \tag{10}$$

Next, consider the equilibrium level of danger

$$\omega^* = \lambda^*\alpha + \mu^*\beta = \alpha F(\gamma_2^*) + (\beta - \alpha)F(\gamma_1^*)$$

We need to show that this expression is greater than

$$\tilde{\omega} = \alpha F(0) + (\beta - \alpha)F(-c')$$

Since  $F(\gamma_2^*) > F(0)$ , it is sufficient to show  $\gamma_1^* \geq -c'$ . From (7), this holds if

$$\frac{\delta(\mu^*v_{\alpha\beta} - \lambda^*v_{\beta\alpha}) - c}{(1 - \lambda^* - \mu^*)(\beta - \alpha) + \lambda^*u_{\alpha\beta} - \mu^*u_{\beta\alpha}} \geq -c'$$

Recall from the proof of proposition 1 that  $u_{\alpha\beta} > 0 > u_{\beta\alpha}$  and  $v_{\alpha\beta} > 0 > v_{\beta\alpha}$ . Hence the above inequality may be written as

$$\delta \geq \frac{c}{\mu^*v_{\alpha\beta} - \lambda^*v_{\beta\alpha}} \left( \lambda^* + \mu^* - \frac{\lambda^*u_{\alpha\beta} - \mu^*u_{\beta\alpha}}{\beta - \alpha} \right) \quad (11)$$

Define

$$\delta^* = \max_{\lambda, \mu} \frac{c}{\mu v_{\alpha\beta} - \lambda v_{\beta\alpha}} \left( \lambda + \mu - \frac{\lambda u_{\alpha\beta} - \mu u_{\beta\alpha}}{\beta - \alpha} \right)$$

subject to  $\lambda \geq 0$ ,  $\mu \geq 0$ ,  $1 \geq \lambda + \mu \geq F(0)$ . Since  $v_{\alpha\beta} > 0 > v_{\beta\alpha}$ , the denominator is always positive and so the maximand is continuous and the maximum exists. For  $\delta > \delta^*$  (11) holds and  $w^* > \tilde{w}$ . ■

**Proof of Proposition 4.** In equilibrium, we must have

$$\lambda = F(\gamma_2) - F(\gamma_1) \text{ and } \mu = F(\gamma_1),$$

so

$$\omega = \alpha F(\gamma_2) + (\beta - \alpha) F(\gamma_1) = \varphi(\omega),$$

where

$$\varphi(\omega) = \alpha F\left(\frac{\delta\omega}{2-\omega}\right) + (\beta - \alpha) F\left(\frac{\delta\omega - 2c'}{2-\omega}\right) \quad (12)$$

Note that  $\varphi'(\omega) > 0$  and that  $\varphi(0) = \alpha F(0) + (\beta - \alpha) F(-c') > 0$ . Also,

$$\begin{aligned} \varphi(\omega) &= \alpha F\left(\frac{\delta\beta}{2-\beta}\right) + (\beta - \alpha) F\left(\frac{\delta\beta - 2c'}{2-\beta}\right) \\ &< \alpha F\left(\frac{\delta\beta}{2-\beta}\right) + (\beta - \alpha) F\left(\frac{\delta\beta}{2-\beta}\right) = \beta F\left(\frac{\delta\beta}{2-\beta}\right) < \beta. \end{aligned}$$

So  $\varphi : [0, \beta] \rightarrow [0, \beta]$ . Any  $\omega$  satisfying  $\omega = \varphi(\omega)$  corresponds to an equilibrium, and any equilibrium must satisfy  $\omega = \varphi(\omega)$ . A decline in  $a$  causes  $F(\gamma)$  to rise for every  $\gamma$ , and clearly shifts  $\varphi(\omega)$  upwards from (12). A rise in the disutility  $\delta$  of being hit, or a decline in the cost  $c$  of greater lethality have exactly the same effect. A rise in lethality  $\beta$  (holding  $\alpha$  constant) also raises  $\varphi(\omega)$  since it raises  $\delta\beta/(2-\beta)$  and lowers  $c'$ . ■

**Proof of Proposition 5.** First, we claim that for all  $q \in [\bar{q}, \hat{q}]$ ,

$$\varphi_1(\hat{\omega}(q), q) \leq 1. \quad (13)$$

Suppose not. Then since  $\varphi(\hat{\omega}(q), q)$  intersects the  $45^\circ$  line at  $\hat{\omega}(q)$ , there is some  $\varepsilon > 0$  such that

$$\varphi(\hat{\omega}(q) - \varepsilon, q) < \hat{\omega}(q) - \varepsilon$$

However  $\varphi(0, q) > 0$ . Hence by continuity there is some  $\omega \in (0, \hat{\omega}(q) - \varepsilon)$  such that  $\omega = \varphi(\omega, q)$ , which contradicts the fact that  $\hat{\omega}(q)$  is (by definition) the smallest equilibrium. Hence we have established (13). Next, suppose that

$$\varphi_1(\hat{\omega}(\hat{q}), \hat{q}) < 1$$

Then there is some  $\varepsilon > 0$  such that

$$\varphi(\hat{\omega}(\hat{q}) + \varepsilon, \hat{q}) < \hat{\omega}(\hat{q}) + \varepsilon.$$

This implies by continuity that there is some  $\theta > 0$  sufficiently small such that

$$\varphi(\hat{\omega}(\hat{q}) + \varepsilon, \hat{q} + \theta) < \hat{\omega}(\hat{q}) + \varepsilon. \quad (14)$$

We know, however, that

$$\varphi(\hat{\omega}(\hat{q}) + \varepsilon, \hat{q} + \theta) > \hat{\omega}(\hat{q}) \quad (15)$$

since  $\varphi$  is increasing in  $q$ . From (14-15), there is for every  $\theta$  sufficiently small some  $\omega \in (\hat{\omega}(\hat{q}), \hat{\omega}(\hat{q}) + \varepsilon)$  such that

$$\varphi(\omega, \hat{q} + \theta) = \omega.$$

Thus  $\hat{\omega}(q)$  is continuous at  $\hat{q}$ . Since this is a contradiction, we have  $\varphi_1(\hat{\omega}(\hat{q}), \hat{q}) = 1$ , and by continuity:

$$\lim_{q \rightarrow \hat{q}^-} \varphi_1(\hat{\omega}(q), q) = 1 \quad (16)$$

Differentiate the identity  $\hat{\omega}(q) = \varphi(\hat{\omega}(q), q)$  totally to obtain

$$\hat{\omega}'(q) = \frac{\varphi_2(\hat{\omega}(q), q)}{1 - \varphi_1(\hat{\omega}(q), q)}$$

From (16), as  $q \rightarrow \hat{q}^-$ , the denominator of this expression approaches zero. By assumption the numerator is positive, and the result follows. ■

## Inferences from the NPD Homicide Log

The NPD homicide log identifies murders with multiple wounds. Most of these murders seem to have two wounds, and our information about number of wounds in multiple-wound murders is incomplete. For our highly stylized exercise we assume that all multiple wound murders have two wounds, and all multiple shot shootings involve two shots. (For 2006 we can identify multiple wound murders only before October 24. Therefore for this exercise we truncate all of our 2006 information at October 24.) We assume: (i) Throughout a year, all gross gun discharge incidents are homogeneous, except for the number of shots fired (either one or two), (ii) When two shots are fired, the probabilities of hitting are independent, and so are the probabilities of being accurate enough to kill if only a single shot were fired, and (iii) If a victim is hit twice he will die. The third assumption biases our results to a finding that multiple shootings lead to many murders and makes the role of multiple shootings more important than if, for instance, we had assumed that only the most accurate shot mattered. This assumption finds some support in Zimring (1972), who found that with the type of guns that are most in use now, almost all multiple wound shootings were fatal. But of course medical technology has improved along with gun technology since the 1970s.<sup>12</sup>

These assumptions let us describe the shooting process with three non-linear equations in three unknown probabilities. These are  $d$ , the probability that an assailant fires two shots;  $h$ , the probability that a shot hits a victim in such a manner that, if it were the only shot to hit him, it would not be fatal; and  $m$ , the probability that a shot hits a victim in such a manner that, if it were the only shot to hit him, it would be fatal. Let  $\mu_2$  denote the empirical ratio of multiple wound murders to shootings in a particular year. (We calculate shootings with and without shots-fired.) In order for a shooting to be a multiple wound murder, the murderer must shoot twice, and both of those shots must hit the victim. Hence

$$\mu_2 = d(m + h)^2 \tag{17}$$

Let  $\mu_1$  denote the empirical ratio of single wound murders to gross gun discharge incidents (with or without shots-fired). A single wound murder could occur two different ways. The murderer could shoot once, and kill; or he could shoot twice, and kill with one shot and miss with the other. Hence:

$$\mu_1 = (1 - d)m + 2dm(1 - m - h). \tag{18}$$

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<sup>12</sup>Since the NPD homicide log is meant as a working tool for investigators, it may have omitted some multiple-wound murders that weren't immediately apparent. We have no reason to believe that these errors changed over the period that we are studying.

Finally, let  $\eta$  denote the empirical ratio of shooting-hits to gross gun discharge incidents. A shooting-hit could occur two different ways. The assailant could shoot once and hit but not kill; or he could shoot twice, with one shot hitting non-fatally and the other missing. Hence

$$\eta = (1 - d)h + 2dh(1 - m - h) \tag{19}$$

We can solve equations (17-19) in each year to find the underlying parameters  $d$ ,  $m$ , and  $h$ . Table 14 shows the results of this exercise. Both versions (with and without shots-fired) tell the same qualitative story. All three parameters generally rise over the period, although not monotonically. The largest percentage increase is in  $m$ , the lethality of an individual shot. The probability  $h$  that an individual shot wounds non-fatally increases the least in percentage terms, while the multiple-shot proportion  $d$  rises by an intermediate percentage.

Table 14: Estimated Parameters of the Multiple Shooting Model (2006 to October 24)

	Including Shots Fired			Excluding Shots Fired		
	$d$	$m$	$h$	$d$	$m$	$h$
2000	0.065	0.053	0.427	0.039	0.085	0.686
2001	0.039	0.091	0.443	0.023	0.141	0.690
2002	0.087	0.070	0.446	0.050	0.115	0.735
2003	0.098	0.081	0.478	0.044	0.121	0.741
2004	0.110	0.081	0.478	0.068	0.126	0.747
2005	0.119	0.087	0.464	0.073	0.135	0.720
2006	0.089	0.096	0.503	0.059	0.140	0.732

Since equations (17-19) are non-linear, percentage changes are not the most illuminating way to think about the contribution of different parameter changes to the rise in murders. Alternatively, we simulated three counterfactual scenarios in which we held one parameter constant at its average value for 2000-2002, let all the other parameters take their actual values, and calculated how many gunshot murders would have occurred in the years 2003 through 2006. The more important a change in parameter has been, the smaller the resulting counterfactual number of murders. The three counterfactual scenarios hold the number of gross gun discharge incidents  $S$  constant (with

or without shots-fired), the single-shot fatality rate  $m$  constant, and the multiple shot proportion  $d$  constant. The results are shown in table 15.<sup>13</sup>

Table 15: Counterfactual Scenarios on Shooting Parameters, 2003-2006:  
Gun Homicides and Projected Counterfactual Gun Homicides (2006 to October 24)

	Including Shots Fired						Excluding Shots Fired					
	Actual	2000-2	$S$	$m$	$d$	Caliber	Actual	2000-2	$S$	$m$	$d$	Caliber
2003	59	49	58	58	58	66	59	49	55	56	57	61
2004	74	49	64	68	65	76	74	49	62	69	66	76
2005	85	49	69	73	74	79	85	49	66	75	74	80
2006	76	40	72	60	71	70	76	40	65	64	70	71

Generally speaking, the rise in multiple shootings has been the least important of these parameter changes, accounting for 7-10 gun homicides a year between 2004 and 2006. The rise in the single-shot fatality rate has been the most important, especially in 2006, when it accounted for 12-20 homicides in the span of ten months. The increase in shootings has been of intermediate importance in this calculation, often being as important as the single-shot fatality rate. The rise in double shootings could be due either to better hardware like semi-automatic weapons, or to greater intensity of shooting. Similarly the rise in the single shot fatality rate could be due either to better hardware like higher caliber weapons, or to greater skill on the part of assailants, or to greater effort on the part of assailants.

In a second simple model with some further assumptions about single-shot non-fatal wound rate, we can isolate the role of better hardware. Assume that all shooters are aiming at the same target, and consider a single shot. If the shooter misses the target by less than  $w$ , a physical constant, the victim is wounded (we are assuming no growth in the body mass of victims during

<sup>13</sup>The  $S$  columns holds gross gun discharges constant at average annual rate for 2000-2002, and use actual ratios of gun homicides to gross gun discharges for 2003-2006. The average 2000-2002 number of gun discharges was 567 including shots-fired and 362 excluding shots-fired. The  $m$  column holds  $m$  (the probability that a single shot is fatal) constant at the average rate for 2000-2002, and uses actual values for other parameters, 2003-2006. The average 2000-2002 value of  $m$  was 0.071 including shots-fired and 0.114 excluding shots-fired. The  $d$  column holds  $d$  (the proportion of shootings with multiple shots) constant at average rate for 2000-2002, and uses actual values for other parameters, 2003-2006. The average 2000-2002 value of  $d$  was 0.064 including shots-fired and 0.037 excluding shots-fired. The Caliber column is explained below.

this period). If the shooter misses by less than  $k < w$ , the victim dies. Our key assumption is that  $k$  depends on the caliber of the weapon (higher caliber weapons imply a larger kill radius  $k$ ), and  $w$  does not depend on the caliber of the weapon. A high caliber bullet that misses entirely has the same effect as a low caliber weapon that misses entirely. Finally, we assume that where shots actually hit relative to the target is distributed normally with zero mean and variance that depends on the skill and effort of the shooter. Let  $\sigma$  denote the standard deviation of shots in any year, and let  $\Phi$  denote the standard normal cumulative distribution function. Then we have

$$\Phi(k/\sigma) - \Phi(-k/\sigma) = m, \tag{20}$$

$$\Phi(w/\sigma) - \Phi(k/\sigma) = \frac{h}{2}. \tag{21}$$

We call  $k/\sigma$  and  $w/\sigma$  the normalized kill and hit radii, respectively. Equation (20) says that single-shot murders occur when a shot hits within  $k$  of the target, and (21) says that non-fatal wounds occur when a shot hits a distance from the target between  $w$  and  $k$ . Solving (20) and (21) yields

$$\frac{k}{\sigma} = \Phi^{-1}\left(\frac{1+m}{2}\right)$$

$$\frac{w}{\sigma} = \Phi^{-1}\left(\frac{1+m+h}{2}\right)$$

These values are shown in table 16.

Table 16: Estimated Parameters of the Target Missing Model (2006 to October 24)

	Including $S_f$		Excluding $S_f$	
	$k/\sigma$	$w/\sigma$	$k/\sigma$	$w/\sigma$
2000	0.066	0.643	0.107	1.203
2001	0.114	0.729	0.178	1.375
2002	0.088	0.700	0.145	1.439
2003	0.102	0.806	0.152	1.483
2004	0.102	0.786	0.159	1.526
2005	0.109	0.757	0.170	1.457
2006	0.121	0.840	0.176	1.522

Two conclusions are immediate from this table. First, since the normalized hit radius is growing, either skill or effort or both is growing. Since  $w$  is a physical constant,  $w/\sigma$  can rise only if  $\sigma$  falls,

and a fall in  $\sigma$  is better marksmanship. Second, since the normalized kill radius is growing faster than the normalized hit radius, caliber must be increasing too. If better marksmanship were the whole story, then  $k$  would be constant and  $k/\sigma$  would fall at the same rate as  $w/\sigma$ ). Thus  $k$  is rising, which is due to higher caliber.

Another counterfactual scenario can help estimate the size of the effect of higher caliber. Essentially, we hold  $k$  constant at its average value of 2000-2002, but let  $\sigma$  and all other parameters evolve as they actually did. We call this the constant caliber scenario. Specifically, we calculate the ratio between average  $k/\sigma$  and average  $w/\sigma$  for 2000 to 2002, and then calculate what  $k/\sigma$  would be in each of the years from 2003 through 2006 if  $w/\sigma$  took its actual value, but the ratio between  $k/\sigma$  and  $w/\sigma$  stayed at its average 2000-2002 value. From these values of  $k/\sigma$  and  $w/\sigma$  we calculate  $m$  and  $h$  for these years, and then calculate how many gun homicides would have occurred with these values of  $m$  and  $h$ . The results are in the last column of table 15. For 2003 and 2004, higher caliber makes no difference to murders in Newark. But for 2005 and 2006, higher caliber seems to account for about half of the gun homicide increase due to the higher single-shot fatality rate, or 5-6 murders per year. By subtraction, better marksmanship also played a significant role in these years.

We have independent confirmation that these estimates are reasonable. For most gun homicides, the NPD learns the caliber of the weapon involved. Generally higher caliber weapons are more common in recent years. From this information, we can make a very rough calculation of changes in the single shot fatality rate. We sort weapons into small, medium, and large caliber, following Wintemute (2000).<sup>14</sup> Zimring (1972) studied the single shot fatality rate for various weapons, and showed that medium caliber weapons were twice as lethal as small caliber weapons. He did not observe many large caliber weapons, as they were rarely used when he was writing. We somewhat arbitrarily assume that large caliber weapons are half again as lethal as medium caliber weapons. Then we can compute average lethality of shots in each year relative to a base year. (Specifically, let  $l_i$  denote the single shot fatality rate from a weapon of class  $i$ , and let  $s_i$  denote the number of homicides by weapons of that class. Then total shootings are  $\sum_i s_i/l_i = S$ , and average lethality is  $\sum_i s_i/S$ .)

Table 17 compares change in estimated average lethality computed in this fashion, relative to the 2000-2002 average, with the extent to which “actual”  $m$  (from table 14) in each year exceeds

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<sup>14</sup>Wintemute (2000) lists .22, .25, and .32 as small caliber; .38, .380, and 9 mm as medium caliber; and .357, .40, .44, .45, and .50 as large caliber.

constant-caliber  $m$ , where caliber is being held constant at the 2000-2002 average. Considering the totally different information used in the two series, and the large number of assumptions that went into calculating both, the degree of congruence is comforting.

Table 17: Estimated Percentage Increases in Average Single-Shot Fatality Due to Higher Caliber Weapons, 2003-2006, Relative to 2000-2002 Average

	Calculated from Caliber	Calculated from Shots	
		Including $S_f$	Excluding $S_f$
2003	-3.9%	-3%	-4%
2004	4.3%	0%	-3%
2005	5.2%	11%	9%
2006	13.3%	11%	9%

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