THE DEER HUNTER: THE UNINTENDED EFFECTS OF HUNTING REGULATIONS

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Abstract—To control the deer population, state game commissions regulate the types of deer that can be legally harvested. These regulations, however, might have an unintended effect on hunting-related accidents by changing the care hunters take when firing their rifles—a moral hazard effect—or changing the composition of hunters. Using detailed data on hunting accidents and regulations in Pennsylvania counties from 1990 to 2005, we find compelling evidence that harvesting restrictions increase the care hunters take in a manner consistent with moral hazard. Thus, these regulations have a positive safety externality.

I. Introduction

EACH year over ten million individuals devote millions of hours to hunting deer and spend an estimated $10 billion on hunting-related equipment and activities.[1] Hunting regulations serve to balance this demand against both the ecosystem effects of deer and the safety of hunters. Regulated hunting is an effective tool for managing and maintaining wild deer populations.[2] At the same time, regulations designed to manage herd size may have unintended effects on hunter safety.

In this paper, we consider the unintended effect on safety of two hunting laws enacted to control and manipulate the deer population. The first allows licensed hunters to harvest (that is, shoot) both bucks and does on the same days during the hunting season. Under this less restrictive harvesting regime, hunters need not distinguish between different types of deer and thereby may take less care prior to firing. Thus, expanding the type of deer that can be harvested may increase the probability of a hunting accident by reducing the care a hunter takes when firing a rifle—a moral hazard effect.[3] The second law creates minimum antler requirements for legally harvesting bucks. Because this law change restricts the type of deer that can be harvested, it may decrease the probability of an accident by increasing the care a hunter takes in firing a rifle. This notion that stricter regulations might lead to a *positive* externality is a departure from the existing research on regulations and moral hazard that primarily focuses on negative behaviors.[4]

To assess the effect of these laws on hunter safety, we rely on a unique panel data set of hunting accidents in Pennsylvania counties from 1990 through 2005. Pennsylvania provides an ideal area for studying the impact of hunting regulation on accidents. The state has more deer hunters (over 900,000) and a larger proportion of deer hunters (9%) than any other (U.S. Department of the Interior, 2004). Moreover, over the sixteen-year period covered by the panel, the two hunting regulations of interest varied over time and across counties.

After describing the institutional details and data in sections II and III, we then turn to the empirical model and results in section IV. Here, we exploit these discrete policy changes to consider whether the probability of a hunting accident varies with restrictions on the types of deer that can be harvested. We separately consider the effect of the law that results from the care a hunter takes in deciding whether to fire his or her rifle from the effect that results from the care taken in maintaining their weaponry. These regulation changes may also affect hunter safety by changing the congestion and composition of hunters. Congestion effects are directly measured by including variables on the number of hunters in the empirical model. Although we do not have data on the composition of hunters' skills or experience, we disentangle moral hazard effects from compositional effects by examining two distinct types of hunting accidents. Accidents due to the mistaken identity of the victim—accidents *related* to moral hazard—are arguably associated with the care hunters take in deciding whether to fire a rifle. Accidents associated with unintentional firings—accidents *unrelated* to moral hazard—are not. In contrast, the composition of hunters influences both types of accidents. In this framework, unrelated accidents serve to identify the effect of compositional changes, and differences between parameters associated with the two types of accidents reveal the moral hazard effect.

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[1] See U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau (2001) for further details.

[2] Deer have few natural predators, and other sources of mortality (such as diseases and injuries) are not sufficient to control populations. Game commissions use hunters to regulate the deer population.

[3] Kreps (1990) writes that the problem of moral hazard arises when one party (such as, hunters) to a transaction may undertake certain actions that affect the other party's (such as regulators') valuation of the transaction but that the second party cannot monitor/enforce perfectly (p. 577).

[4] In the context of regulatory environments, empirical evidence of moral hazard is found in response to seat belt use (Peltzman, 1975), safety caps on medicine bottles (Viscusi, 1984), prescription drug insurance (Coulson et al., 1995), thrifts' deposit insurance (Grossman, 1992), and automobile insurance (Cohen & Dehejia, 2004). Hubbard (1998) even finds evidence of moral hazard in the vehicle inspection market. Cohen and Einav (2003), in contrast, find no evidence that mandatory seat belt laws increase reckless driving. Labor markets are the setting for another set of empirical tests of moral hazard. Using differences in contractual arrangements, this literature finds evidence of moral hazard by physicians (Gaynor & Gertler, 1995), farmers (Foster & Rosenzweig, 1994), and professional football players (Conlin & Emerson, 2003).

TABLE 1.—HUNTING REGULATIONS

	1990–1997	1998–1999	2000	2001	2002–2005
Primary deer hunting season	Twelve days buck only followed by three days of doe only	Twelve days buck only followed by three days of doe only	Eleven days buck only followed by one day both buck and doe followed by two days of doe only	Twelve days where both buck and doe can be harvested	Twelve days where both buck and doe can be harvested
Different regulations for youth and senior hunters	None	Can harvest both buck and doe the first and second Saturday of season	Can harvest both buck and doe the first Saturday of season	None	None
Antler requirements for buck	2 or more pts	2 or more pts	2 or more pts	2 or more pts	3 or more pts, 51 counties 4 or more pts, 10 counties

Game laws in Pennsylvania provide a clear empirical setting in which to assess the extent of moral hazard. Still, one might not expect to find any noticeable effect of these regulations on hunting accidents. After all, accidents are rare events (in general, fewer than 25 per hunting season) by which to measure changes in behavior, and the probability of being caught violating a restriction is often quite small. Despite these concerns, we find compelling evidence that hunters react to changes in the probability of violating game regulations consistent with moral hazard, and limited evidence that these game regulations also affect hunter composition. In particular, our point estimates suggest that allowing both bucks and does to be harvested had the unintended consequence of increasing the probability of a *related* accident, while the more stringent antler restrictions decrease the probability of a *related* accident. These results are consistent with hunters changing their level of care in response to the regulation changes. Using unrelated accidents as an outcome measure, we find the opposite effect of the regulations: our point estimates suggest that the probability of an *unrelated* accident decreased after allowing both bucks and does to be harvested and increased with more stringent antler restrictions. Together, the results on unrelated and related accidents suggest that, while the law changes may have altered the composition of hunters, the regulations affected the care hunters take when firing their rifles in a manner constant with moral hazard.

II. Institutional Details

In 1721, the Pennsylvania House of Representatives passed the nation's first game laws to protect the whitetail deer. Today, Pennsylvania deer hunting laws restrict the types of game that can be harvested on particular days with particular weaponry. We focus on the deer hunting with rifles that occurs in the three-week period starting the Monday after Thanksgiving.[5] During this period, regulations restricting the types of deer that can be harvested by licensed hunters vary by day, by county, and by the age of the hunter. While the basics have remained stable for some time, the particulars have varied.

Table 1 summarizes the Pennsylvanian deer hunting regulations from 1990 through 2005. Prior to 1998, only bucks could be harvested throughout Pennsylvania the first two weeks after Thanksgiving (referred to as "buck season").[6] After these twelve days, there were three days where hunters could harvest only does (referred to as "doe season").[7] From 1998 to 2000, these same rules applied for hunters ranging from age 16 to age 65, but young and senior hunters could harvest both bucks and does for some parts of the "buck season." In 2000, the Pennsylvania Game Commission allowed all hunters to hunt both bucks and does the last day of "buck season" and allowed only two subsequent days for hunters to harvest only does. After 2000, all hunters could harvest both bucks and does throughout the entire twelve-day hunting season. The goal of this regulation change was to decrease the doe population relative to the buck population and increase the age of the buck population in order to establish a "more natural breeding ecology" (see the 2004 Pennsylvania Hunting Digest).

When harvesting bucks, there are antler restrictions. In all years prior to 2002, the Pennsylvania Game Commission required at least one of the buck's antlers to have a minimum of two points, a very minimal restriction in that most antlered bucks satisfy this antler requirement.[8] Beginning in 2002, the Game Commission imposed more stringent antler requirements. Ten counties required a minimum of four points on at least one antler and the other 51 counties required a minimum of three points on at least one antler. As stated in the Pennsylvania Game Commission's Deer Management Program's 2004 Game News: "The objectives of these new restrictions are designed to protect about half of the yearling bucks from being taken during the hunting

[5] This is the primary deer hunting season where the large majority of deer are harvested.

[6] To be precise, "buck season" is when only deer with antlers can be harvested and "doe season" is when only anterless deer can be harvested. Very young bucks do not have antlers and can therefore be harvested in "doe" season.

[7] The Pennsylvania Game Commission prohibited hunting on Sundays.

[8] A 2001 sampling done by the Pennsylvania Game Commission suggests that 75% to 80% of all bucks (including antlerless bucks) satisfy this two-point requirement.

season and yet have most adult bucks legal. Throughout most of the state, a 3-points to a side restriction should satisfy this objective. In western Pennsylvania, however, a 3-point restriction would protect less than a third of all yearling bucks, whereas a 4-points to a side restriction protects more than half."

These regulations are enforced by the Pennsylvania Game Commission, which employs a force composed of approximately 200 full-time wildlife conservation officers and close to 700 deputy officers. In addition to assisting in wildlife research and education projects, officers enforce hunting and trapping laws and investigate hunting accidents. An officer's area of responsibility is about 350 square miles (Pennsylvania Game Commission, 2006). As with most policing, effective enforcement strategies often involve engaging concerned citizens, and the Game Commission actively encourages hunter participation in monitoring and reporting violations. Hunters are asked to report violations to game officers, a toll-free phone line is devoted to citizen reporting, and in some cases rewards are offered for relevant information.[9]

To effectively manage and enforce the game regulations, the commission requires hunters to obtain a general hunting license to harvest antlered deer during the season, and a different county-specific license to take an antlerless deer.[10] Each licensed hunter is provided with the Pennsylvania Hunting Digest (Pennsylvania Game Commission, 1990–2006), which describes the procedures and penalties for violating a game restriction. Hunters killing a protected deer are required to deliver the carcass to the Game Commission and to provide a written statement about the violation. An officer then determines whether the kill was an accident, in which case the penalty is nominal ($25 in 2003), or a result of carelessness, in which case the penalty can be substantial (a minimum of $500 in 2003). Notice that in addition to the fine, hunters who violate these regulations must also incur the cost of transporting the entire carcass to a Game Commission officer.[11] Failing to report a violation can also lead to a substantial fine (a minimum of $500 in 2003). Besides the fine, carelessness and failing to report a violation can result in the hunter's license being revoked for multiple years.

Each year, the Game Commission issues thousands of citations and warnings. During calendar year 2003, for example, the Game Commission prosecuted 8,333 cases and issued 12,532 warnings (Pennsylvania Game Commission, press release, 2004a). A total of $1,540,444 in penalties was assessed, averaging $184.86 per violation. Many of the citations involve violations of the management restrictions focused on in this paper. For example, in 2003 conservation officers handled 2,096 mistaken kills of antlered deer, of which 2,050 resulted in hunters paying a $25 administrative fee and surrendering the antlers. Of the remaining 46 cases, the officers rejected the mistake kill claims and issued a $500 fine.

III. Data

To identify the effects of regulations on accidents, we require detailed information on hunting-related accidents. The Hunter-Trapper Education Division of the Pennsylvania Game Commission has a detailed description of each reported hunting accident that occurred in Pennsylvania from 1990 through 2005. Using these descriptions, we assemble a unique panel of hunting accidents from 1990 through 2005 for 61 of the 67 counties in Pennsylvania. The six "Special Regulation" counties in the Philadelphia and Pittsburgh metropolitan areas, which have different regulations and different available information, are excluded from our empirical analysis. For each accident, we observe the date and county of the incident. Thus, we have outcome data on whether there was a hunting accident for all 13,664 county-days of rifle deer hunting season during the sixteen-year period.

We further disaggregate these data using information on the cause of each accident. To help assess whether accident rates are sensitive to game regulations because hunters take less care to distinguish their prey or because the regulations cause a change in the composition of hunters, we create two outcome variables for each county-day: accidents related and unrelated to moral hazard. Related accidents include those not self-inflicted and reportedly caused when the victim is shot as game, as well as those caused by a ricochet, a stray bullet, or because the victim was in the line of fire. These accident classifications are those most likely provided by hunters who have accidentally shot another person as game.[12] Of the 148 accidents classified as related, 21 indicate the cause to be shot as game, 19 indicate a ricochet, 20 indicate a stray bullet, and 88 indicate that the victim was in the line of fire. Self-inflicted and all other accident causes

[9] The 2002 Pennsylvania Hunting Digest has a section entitled "Reporting a Violation" that provides a "Violation Report Form" and states: "Immediately after witnessing a suspected violation, note as many details as possible. The more information you provide, the faster a violator may be caught and prosecuted. Transmit this information to the Commission region office serving your area as quickly as possible. . .Gather as much information as possible about the suspect: an accurate physical description and any other pertinent information. If possible, get a hunting license number. Try to secure names and addresses of other witnesses, and any information they may have about the violation or suspect." For an example of a case prosecuted based on citizen reporting, see http://www.pgc.state.pa.us/pgc/cwp/view.asp?A=11&Q=155522.

[10] The price of a hunting license for an adult increased from $12.75 in 1990 to $20 in 2005. The price of a doe license for an adult increased from $5.50 in 1990 to $6 in 2005. The Pennsylvania Game Commission allocates to each county a certain number of doe licenses per season. These doe licenses are allocated through a lottery and, if all licenses are not purchased through this lottery, hunters may purchase a second doe license.

[11] The carcass often weighs well over 100 pounds and the Game Commission office could be many miles from the kill.

[12] Hunters may have incentives to misreport details for accidents resulting from the victim being mistaken as game. We find similar results when related accidents are defined as either victim in line of fire or victim shot as game (not a ricochet or a stray bullet).

TABLE 2.—DESCRIPTIVE STATISTICS

	Means and Standard Deviations
Fraction of county-days where an accident related to moral hazard occurred	0.011 (0.102)
Fraction of county-days where an accident unrelated to moral hazard occurred	0.014 (0.119)
Fraction of county-days where all hunters can harvest only buck	0.518 (0.500)
Fraction of county-days where all hunters can harvest only doe	0.143 (0.350)
Fraction of county-days where only youth and/or seniors can harvest both buck and doe	0.067 (0.250)
Fraction of county-days where all hunters can harvest both buck and doe	0.272 (0.445)
Minimum of two points on buck's antler	0.786 (0.410)
Minimum of three points on buck's antler	0.182 (0.386)
Minimum of four points on buck's antler	0.032 (0.177)
Average daily number of hunters	7,970 (3,446)
Forested land (square miles)	452 (235)
Congestion = average daily number of hunters divided by forested land	21.13 (11.52)
Deer population	13,898 (7,138)
Average daily number of bucks harvested	185.4 (97.3)
Average daily number of does harvested	272.0 (169.7)
Total number of county-days	13,664

are classified as unrelated to the moral hazard issue. The causes stated for these unrelated accidents include sports arm in dangerous position, unintentional discharge, hunter slipped or fell, hunter dropped sports arm, sports arm defective, used sports arm as club, and other. These unrelated accidents generally occur from careless handling of the rifle, as opposed to related accidents that occur because of mistaken identity.

Table 2 reveals the means and standard deviations for the variables used in this study. As expected, the probability of a county having a reported hunting accident on a given day is quite low. The fraction of county-days where an accident related to moral hazard occurs is 0.011, while the fraction with an accident unrelated to moral hazard is 0.014.[13]

Figure 1 depicts the total number of related and unrelated accidents by year from 1990 through 2005. For both types of accidents, the total number appears to trend downward across years. Given our interest, the accident rates in 2000–2005 are the most notable feature of the figure. In 2000, concurrent with allowing all hunters to harvest both bucks and does on certain days, there is a sharp increase in the number of related accidents, and in 2002, concurrent with the more stringent antler requirements, there is a pronounced drop in the number of accidents. In the context of unrelated accidents, 2000 was the start of a qualitative shift in the ordering of related and unrelated accident rates, with the number of related accidents exceeding the number of unrelated accidents. This shift, however, is short lived. In 2002 and 2003, following the changes to the antler requirements, the number of unrelated accidents exceeds the number of related accidents, yet by 2004 and 2005 the ordering is reversed again.[14]

Interestingly, one might expect the antler requirements to have a differential impact over time that is consistent with the observed variation in related accidents. In particular, as designed, the buck population increased in age from 2001 to 2005, and thus the fraction of bucks with fewer than three (or four) points fell over this period.[15] Thus, the care taken to identify a legal buck should decrease over time. As revealed in figure 1, the number of related accidents falls sharply in 2002 and is less in 2002 than in 2003 through 2005. While undoubtedly some of these annual fluctuations reflect year-to-year randomness in a rare outcome, variation in the number of related accidents is strikingly consistent with the hypothesized moral hazard effects associated with the changes in the antler requirements.

The key independent variables that pertain to moral hazard are antler restrictions and the types of deer (that is, bucks and/or does) that can be harvested by the age of the hunter (youth/senior or all). The summary statistics in table 2 reveal the fraction of county-days under each regime. Over the sixteen-year period, hunters could legally harvest only bucks in 51.8% of the county-days and only does in 14.3%. For 6.7% of the county-days, youth and seniors could harvest both bucks and does. In the remaining 27.2% of the county-days, all hunters can harvest both bucks and does.[16] Antler restrictions beyond two points were instituted in 2002, resulting in 78.6% of the county-days having a minimum antler requirement of two points.

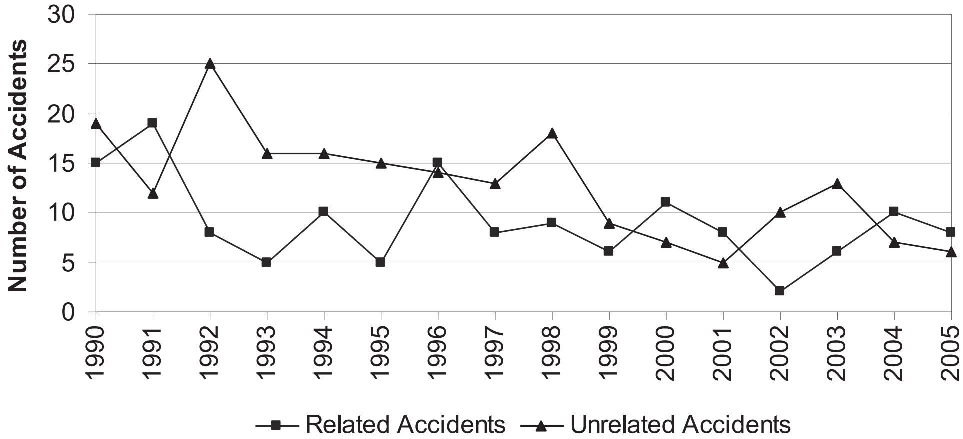
[13] No county-day has more than one related accident and eight county-days have more than one unrelated accident occur. In all eight cases, there were two unrelated accidents that occurred.

[14] Along with graphically depicting these qualitative shifts in the ordering of related and unrelated accidents, we can test whether the difference between the number of related and unrelated accidents is statistically different before and after the law changes. Using a standard *t*-test, we can reject the null hypotheses that this difference is the same in 1998–1999 as it is for 2000–2001 and that this difference is the same in 2000–2001 as it is for 2002–2003.

[15] See the Pennsylvania Game Commission's State Wildlife Management Agency winter 2005 research update for a summary of the Buck Survival and Movement Study. The change in the herd age distribution documented in this study can be attributed to the facts that (i) preventing bucks with two points from being harvested in prior years resulted in an older buck population and (ii) the large doe harvests in 1999 through 2003 (due in part to the concurrent buck and doe seasons) resulted in fewer fawns being born in 2003 through 2005.

[16] For related (unrelated) accidents, one (five) of the 15 (27) in 1998 and 1999 occurred on the two Saturdays of "buck season" where youth and seniors could harvest both bucks and does. In 2000, five of the eleven related accidents and only one of the seven unrelated accidents occurred on the last day of "buck season" when all hunters could harvest both bucks and does.

FIGURE 1.—TOTAL RELATED AND UNRELATED ACCIDENTS



While the panel data allow us to control for county-specific factors that are fixed over time, other factors that may vary over time can confound any observed association between game regulations and accident rates. In particular, we include an indicator variable that accounts for the only law change specifically related to safety between 1990 and 2005. Beginning in 1991, hunters are required to wear at least 250 square inches of fluorescent orange clothing.

We also account for specific trends in hunting, including the average daily number of hunters, the congestion of the hunting area, the deer population, and the number of deer harvested.

The Wildlife Management Division of the Pennsylvania Game Commission estimates the number of hunter-days (total number of days spent hunting deer for all hunters). These measures are annual, not daily, county-level counts for years prior to 2003.[17] After 2002, the Pennsylvania Game Commission changed the geographic designations from which they collected hunter-day information from county to Wildlife Management Units (WMUs). Using the information from the 22 WMUs, we estimate county-level hunter-days for 2003 through 2005 by assuming a common growth in hunter-days across years for counties in the same WMU.[18] We take these annual counts for each county and divide them by the number of hunting days in the season to obtain the average daily number of hunters per county. To account for days that might be particularly populated, we control for whether the day is the first day of the hunting season, whether the day was the first or second Saturday of hunting season, whether the day is the first day (Monday) of doe season, and the number of days since the start of hunting season.

While the average daily number of hunters per county is 7,970, this average trended upward in the 1990s, increased significantly in 2000 and 2001, and then decreased even more significantly after 2001 (see table 2 and figure 2). This increase in 2000 and 2001 reflects the shorter hunting season (14 and 12 days compared with 15 days), not an increase in the total number of hunters in the season. As figure 2 depicts, the total numbers of hunter-days decreases significantly after 2000 and plateaus at approximately 85,000 from 2003 through 2005.

In addition to accounting for the average daily number of hunters, we also divide average daily number of hunters by square miles of forested land for each county-year to construct a hunter congestion measure.[19] Arguably, the impact of regulations on related accidents is sensitive to the degree of hunter congestion. At the most basic level, the numbers of hunters who can be mistaken as game increase with the level of congestion. Moreover, if citizens serve to monitor and report on mistaken kills, one might expect the probability of a violation being reported to be greater in more congested areas. This would result in the effect of the regulations on related accidents to be greater in more congested areas.

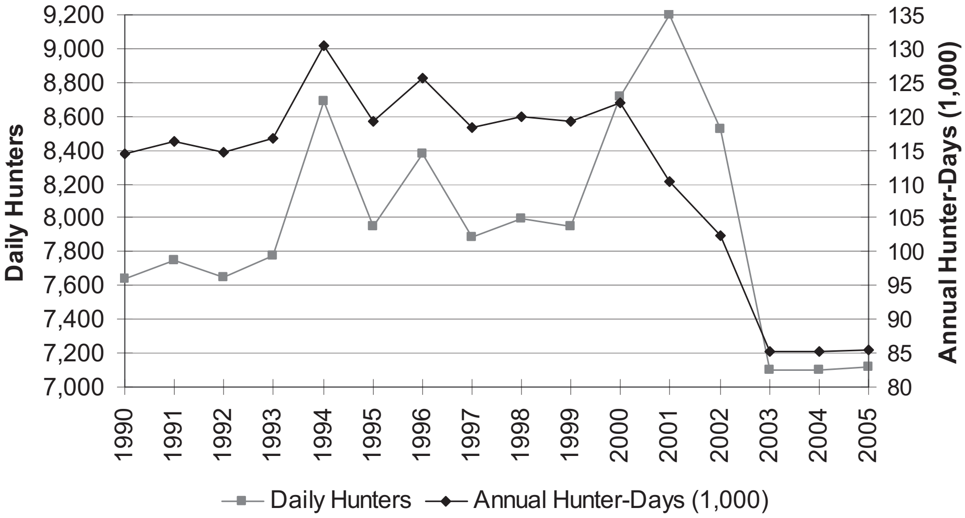
Along with accounting for the number of hunters, we also want some measure of the number of shots being fired per day. As with hunter-days, we have county-level information on the numbers of bucks and does harvested each year and, therefore, divide these numbers by the number of hunting days in the season to obtain average daily harvests at the

[17] The annual number of hunter-days includes hunting during the three-week period starting the Monday after Thanksgiving as well as during the muzzleloader, flintlock, and archery seasons. Well over 90% of the hunter-days occur during the three-week period immediately after Thanksgiving.

[18] For those counties residing in multiple WMUs, we estimate hunter-days by taking a weighted average of the WMU growth rates where the weights are based on the fraction of the county located in the different WMUs. The Pennsylvania Game Commission did not collect the information required to calculate the number of hunter-days in 2004. Therefore, we estimate the 2004 county-level hunter-days by linearly interpolating the 2003 and 2005 hunter-day data.

[19] The Wildlife Management Division provided the forested land data obtained from the United States Forest Service Survey. This survey provides county-level information in 1981, 1991, and 2001. Annual county-level numbers are estimated by linearly interpolating and extrapolating this information. Our basic findings do not change when the congestion measure is based on acres of gamelands and acres of gamelands excluding farmland.

FIGURE 2.—DEER HUNTERS



county level.[20] We proxy for shots taken in a day using these average daily harvests of bucks and does as well as the overall deer population.[21]

Table 2 reveals an average herd size of 13,898 per county and average daily numbers of bucks and does harvested in a county of 185.4 and 272.0, respectively. Figure 3 displays the average and total daily harvests of bucks and does for each year from 1990 to 2005. The law change that allowed the harvesting of both bucks and does is contemporaneous with a dramatic increase in daily doe harvests. After 2002, the daily and total doe harvests return to levels similar to pre-2000 levels. As for daily buck harvest, it trended slightly upward prior to 2001, increased more dramatically in 2000 and 2001 (when the concurrent seasons were introduced), and then decreased in 2002–2005 when more stringent antler requirements were put into effect. Total buck harvest in a season tended to increase slightly across years until 2001 and decreased after 2001. As might be expected, the largest percentage drop in the harvest occurs simultaneously with the 2002 introduction of the more stringent antler requirements.

[20] In 2005, the Pennsylvania Game Commission changed the geographic designations from which they collected harvest information from county to WMU. We estimate the 2005 county-level harvest numbers from the WMU information using the same procedure as with the hunter-day county-level estimates.

[21] The Wildlife Management Division estimates county-year harvests based on those who report a kill as well as Game Commission checks of butcher shops and hunting camps. At the end of each hunting season, the Wildlife Management Division estimates deer population for each county using a model of reproductive rates and accounting for the number and type (both gender and age) of deer harvested. We define the deer population in a given year as the population that existed at the end of the prior year's hunting season. Based on this definition, the deer population increased significantly in 1999. The deer population averaged 12,792 per county prior to 1999 and averaged 15,607 per county between 1999 and 2004. The Wildlife Management Division did not provide deer population estimates at the end of the 2004 hunting season due to "weaknesses in modeling procedures" (see Pennsylvania Game Commission, 2004b, p. 3). We assume the county-level 2005 deer population estimates are the same as the 2004 estimates.

IV. Empirical Evidence

To evaluate whether the observed relationships between hunting regulations and accidents found in figure 1 are sensitive to other confounding factors, we estimate a series of bivariate probit models that account for observed and unobserved county-specific characteristics. In section IV-A, we outline the basic-fixed effect model that explicitly accounts for county-specific factors that may be related to both game regulations and accident rates. In section IV-B, we present and discuss the estimates.

A. Model

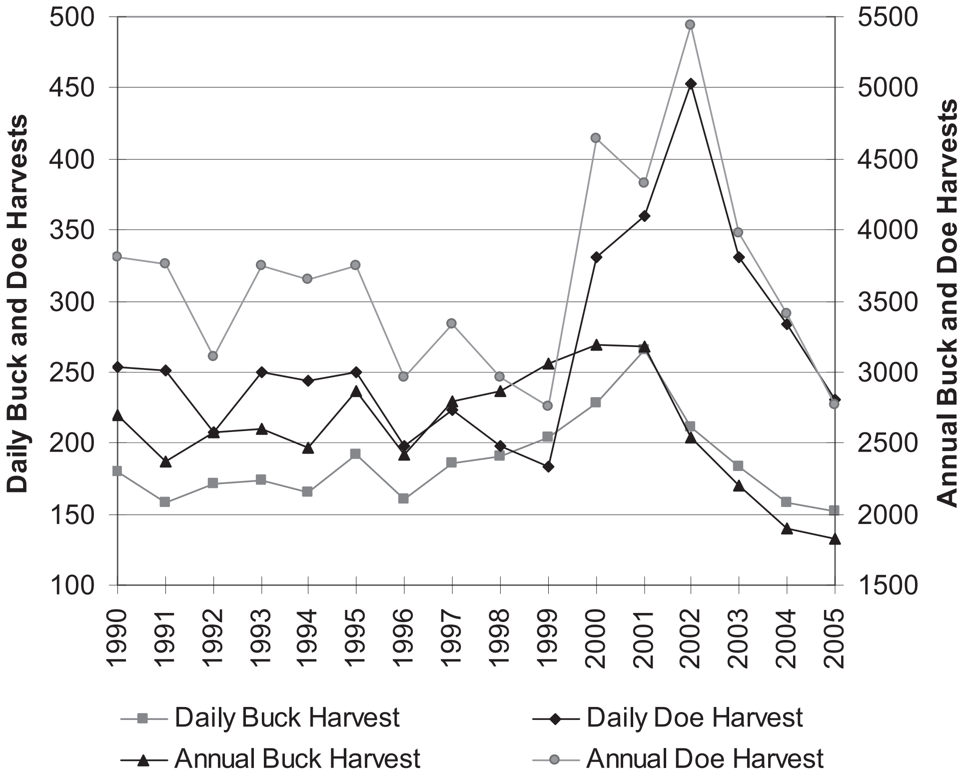
To assess whether hunting accidents are sensitive to game regulations aimed at managing the deer population, let the latent variables y_{1id}^* and y_{2id}^* represent the care hunters in county i on day d take in shooting and maintaining their weaponry, respectively. Let

$$y_{rid}^* = Z_{id}\beta_r + X_{id}\theta_r + \alpha_{ri} + \nu_{rid} \text{ for } r = 1,2,$$

where Z is a vector of indicator variables reflecting the different regulation regimes, X is a vector of other observed covariates, and (β, θ) are unknown parameters. To account for county-specific, time-invariant unobservables that may affect the care in shooting and maintaining their weaponry, we include county-specific fixed effects (α_{ri}). These county-specific effects capture such things as the number of experienced hunters that hunt annually in a given county and the hunter education program in the county. Finally, the unobserved random variable, ν_{rid}, is assumed to be standard normally distributed conditional on the regressors. We allow ν_{1id} to be correlated with ν_{2id}.

The vector Z includes five distinct indicators of different policy regimes: a dummy equal to 1 if a minimum of four points is required on at least one antler, a dummy equal to 1 if the minimum is three points, a dummy equal to 1 if only

FIGURE 3.—BUCK AND DOE HARVESTS



youth and seniors can harvest both bucks and does, a dummy equal to 1 if all hunters can harvest both bucks and does, and a dummy equal to 1 if hunters can harvest only does. The excluded categories are two-point bucks and periods where all hunters can harvest only bucks. The vector X_{id} includes measures of the deer population; the daily numbers of bucks and does harvested; daily number of hunters; our measure of congestion; a set of indicator variables identifying whether it was the first Saturday, second Saturday, first day of the hunting season, or first day of doe season; the number of days from the start of the hunting season; an indicator variable identifying whether hunters must wear 250 square inches of fluorescent orange clothing; and year (to capture trends in accidents over time).

Although the latent measures of hunter care in shooting and maintaining firearms are unobserved, we do observe whether there is an accident in county i on day d. Let $y_{1id} = 1$ if there was a related accident in county i on day d ($y_{1id} = 0$ otherwise) and $y_{2id} = 1$ if there was an unrelated accident in county i on day d ($y_{2id} = 0$ otherwise). Assume the following bivariate probit model:

$$y_{1id} = 1 \text{ if } y_{1id}* > 0 \text{ and } = 0 \text{ if } y_{1id}* \leq 0,$$

$$y_{2id} = 1 \text{ if } y_{2id}* > 0 \text{ and } = 0 \text{ if } y_{2id}* \leq 0.$$

We estimate the parameters (β_r, θ_r, and α_{ri}) using maximum likelihood estimation. In our basic specification, we assume the effect of game regulations is the same in all counties across all years.

Two related models are considered to further assess the robustness of our findings. First, we consider a model that allows the effect on accidents of the antler restrictions to depend on whether it is the first year (that is, 2002) of the restrictions. As noted above, the effect on related accidents should be most pronounced immediately after the antler restrictions are imposed when the fraction of bucks meeting the new restriction is relatively small. Given that the 2002 interaction is identified off a single year of data, and that the year-to-year variability in accidents can be substantial, we would not want to place too much emphasis on the results from this model. Nevertheless, this model should provide evidence on whether descriptive results displayed in figure 1 continue to hold in the regression model.

Finally, we present results from a model that interacts the measure of congestion with whether a hunter can harvest both bucks and does as well as with the point restriction. As discussed in section III, the differential effect of these regulations on related and unrelated accidents may vary with congestion.

B. Results

The first two columns in table 3 (model 1) contain the coefficient estimates associated with the basic bivariate

TABLE 3.—BIVARIATE PROBIT SPECIFICATIONS (N = 13,664 COUNTY-DAYS)

	Model 1			Model 2			Model 3		
	Related Accident	Unrelated Accident	SS	Related Accident	Unrelated Accident	SS	Related Accident	Unrelated Accident	SS
Minimum of four points on buck (indicator variable)	−0.226	0.531*	*				−0.556	0.709	
	(0.288)	(0.294)					(0.638)	(0.550)	
Minimum of three points on buck (indicator variable)	−0.280	0.246	*				−0.471	0.337	
	(0.222)	(0.225)					(0.374)	(0.333)	
(Minimum of four points on buck) × (indicator variable for year 2002)				−5.818**	0.073	**			
				(0.392)	(0.434)				
(Minimum of four points on buck) × (indicator variable for years 2003–05)				0.017	0.674**				
				(0.309)	(0.319)				
(Minimum of three points on buck) × (indicator variable for year 2002)				−0.509*	0.210	*			
				(0.309)	(0.243)				
(Minimum of three points on buck) × (indicator variable for years 2003–05)				−0.140	0.297				
				(0.259)	(0.257)				
Youth and/or senior harvest bucks and does (indicator variable)	0.136	−0.037		0.142	−0.033		0.164	−0.045	
	(0.193)	(0.153)		(0.194)	(0.154)		(0.193)	(0.154)	
All hunters can harvest bucks and does (indicator variable)	0.657**	−0.147	**	0.638**	−0.156	**	0.294	0.037	
	(0.187)	(0.208)		(0.191)	(0.210)		(0.320)	(0.300)	
All hunters harvest only doe (indicator variable)	1.208**	0.737**		1.210**	0.740**		1.238**	0.740**	
	(0.257)	(0.241)		(0.257)	(0.241)		(0.255)	(0.241)	
Deer population (1,000)	0.041**	−0.046**	**	0.035*	−0.048**	**	0.042**	−0.045**	**
	(0.017)	(0.016)		(0.018)	(0.017)		(0.017)	(0.016)	
Average daily number of bucks harvested (1,000)	−2.031*	2.258**	**	−1.626	2.343*	**	−3.030**	2.768**	**
	(1.364)	(1.115)		(1.499)	(1.244)		(1.417)	(1.205)	
Average daily number of does harvested (1,000)	−0.657	0.069		−0.524	0.152		−0.592	−0.017	
	(0.547)	(0.515)		(0.573)	(0.520)		(0.553)	(0.526)	
Average daily number of hunters (1,000)	0.069	−0.030		0.079	−0.022		0.030	−0.017	
	(0.062)	(0.047)		(0.061)	(0.047)		(0.061)	(0.048)	
Congestion in forested land = (ave. daily number of hunters/forested land × 1,000)	−0.025	0.004		−0.022	0.005		−0.032	0.010	
	(0.022)	(0.017)		(0.022)	(0.017)		(0.032)	(0.025)	
First Saturday in season (indicator variable)	0.197	0.638**	**	0.196	0.638**	**	0.197	0.639**	**
	(0.147)	(0.100)		(0.147)	(0.100)		(0.147)	(0.100)	
Second Saturday in season (indicator variable)	0.909**	0.898**		0.914**	0.900**		0.921**	0.903**	
	(0.213)	(0.192)		(0.213)	(0.192)		(0.211)	(0.191)	
First day of season	0.339**	0.579**		0.342**	0.579**		0.333**	0.578**	
	(0.134)	(0.112)		(0.134)	(0.112)		(0.134)	(0.112)	
Day of hunt season	−0.094**	−0.095**		−0.094**	−0.095**		−0.096**	−0.095**	
	(0.023)	(0.021)		(0.023)	(0.021)		(0.023)	(0.021)	
First day of doe-only season	0.605**	0.372**		0.605**	0.372**		0.606**	0.372**	
	(0.138)	(0.168)		(0.138)	(0.168)		(0.139)	(0.168)	
Wear orange fluorescent clothing (indicator variable)	−0.075	0.009		−0.050	0.015		−0.112	0.021	
	(0.148)	(0.131)		(0.148)	(0.132)		(0.150)	(0.131)	
Year	−0.032*	−0.026*		−0.038**	−0.028*		−0.024	−0.029*	
	(0.018)	(0.016)		(0.018)	(0.017)		(0.018)	(0.016)	
(All hunters can harvest buck or doe) × (congestion in forested land)							0.020*	−0.010	**
							(0.011)	(0.009)	
(Minimum point requirement for bucks) × (congestion in forested land)							0.005	−0.003	
							(0.011)	(0.010)	
county fixed effects	YES	YES		YES	YES		YES	YES	
Log likelihood	−1,522			−1,518			−1,517		
ρ	0.10			0.10			0.10		

Notes: The standard errors in parentheses are robust to arbitrary heteroskedasticity. *Statistically significant at .10 level; **statistically significant at .05 level. The SS column denotes whether we can reject the null that the corresponding coefficients in the related and unrelated accident probits are equal.

probit. The evidence is consistent with the notion that more restrictive regulations decrease the probability of a related accident. In particular, we find that the three- and four-point antler requirements reduce the probability of a related accident (coefficients of −0.280 and −0.226, respectively). Likewise, we find that regulations allowing youth and seniors to harvest both bucks and does, and allowing all hunters to harvest both bucks and does, increase the probability of a related accident (coefficients of 0.136 and 0.657, respectively). While all of these estimates point to similar qualitative effects, only the parameter associated with all hunters allowed to harvest both bucks and does is statistically significant.

To disentangle moral hazard effects from other explanations, such as changes in the composition of hunters, we turn to the effect of the regulations on unrelated accidents. The coefficient estimates in column 2 of table 3 reveal qualitatively different effects of the regulations on the probability of an unrelated accident. In particular, more restrictive regulations lead to a modest (and generally statistically insignificant) increase in the accident rate. Thus, these estimates are consistent with the notions that (i) more stringent antler requirements changed the composition of hunters in such a manner as to increase the probability of an unrelated accident and (ii) fewer restrictions on the type of deer allowed to be harvested decreased this probability.

Perhaps the most striking findings from model 1 are the qualitative differences in the effect of these regulations on the two outcome measures. Restrictive regimes appear to increase the probability of unrelated accidents and decrease the probability of related accidents. Moreover, these substantive differences are statistically significant. This suggests that while the regulations may have changed the composition of hunters, the changes also altered the care a hunter takes when distinguishing a fellow hunter from a deer in a manner consistent with moral hazard.

To give some content to the findings, it is useful to compare the predicted probability of a related accident with and without the particular restriction. To do this, we compute the estimate of the accident probability with and without the regulation of interest for each county-day, holding fixed all other covariate values. Conditional on being able to harvest bucks, the average estimated probability of a related accident decreases from 0.010 to almost 0.005 when the antler requirement increases from two to three or four points. Likewise, the accident probability increases from 0.009 to 0.022 when all hunters are allowed to harvest both bucks and does during the same period. This probability increase suggests that the expected annual number of related accidents would have increased from 9.9 to 23.0 if both bucks and does could have been harvested during the 1990 through 1999 hunting seasons. The fact that approximately 15% of these related accidents are fatal suggests that allowing hunters to harvest both bucks and does throughout the 1990s would increase the expected number of hunting deaths from 14.8 to 34.5.

These estimates imply that moral hazard plays an important role in understanding the behavioral impact of game regulations. Still, there is much uncertainty about the specific effects. On the one hand, given the limited number of hunting-related accidents, we would expect that these parameters are not precisely estimated. In fact, as noted above, few of the point estimates reported in table 3 are statistically different from 0 and, as such, the estimated accident probabilities are not statistically different from each other across the two regimes.

On the other hand, the evidence from unrelated accidents implies that the estimated effect may be downward biased. While the estimates on related accidents will confound the effects arising from moral hazard and from changes in the composition of hunters, the impact of regulations on unrelated accidents provides direct evidence on the compositional effects. The estimates for unrelated accidents suggest a compositional change in hunters that opposes the moral hazard effect in the probit for related accidents. These qualitative differences, as noted above, are statistically significant. Thus, the marginal effect of these regulation changes on the care hunters take when firing is likely to be greater than the effects noted above. That is, the estimates associated with related accidents provide a lower bound on the moral hazard effects of game regulations.

One notable result in table 3 is the positive coefficient estimate associated with the variable indicating hunters can legally harvest only does in the related accident regression. All else equal, one would not expect the care a hunter takes to depend on whether he can harvest only bucks or only does, and we would expect the coefficient associated with the doe-only variable to be 0. In fact, the expected probability of an unrelated accident is also higher on days when all hunters can harvest only doe compared to only buck. Furthermore, we cannot reject the null hypothesis that the coefficient estimates associated with the doe-only regulation variable in the related and unrelated accident regressions are equal. These results seem to reflect the limitations of our measures of hunting activity and our lack of hunter composition information. From 1990 through 1999, nearly all doe hunting occurred during the last few days of the season, and more deer are harvested on these days than during the two-week buck season. Given this concentrated harvest, it seems likely that the number as well as types of hunters differ across the seasons. For example, to the extent that hunters are interested in harvesting a single deer for venison, those left hunting during the final three days may be less skilled/experienced than those who were successful during the buck season. In any case, it seems likely that the level of congestion and the number of shots fired varies across the buck-only and doe-only seasons. Our measures of the number of hunters, congestion, and harvests, however, are based on annual rather than daily data. Thus, the coefficient on the doe-only regulation variable in the probits for related and unrelated accidents may simply reflect more total hunters and a larger fraction of inexperienced hunters.

In fact, other coefficient estimates point to the importance of specific periods in the hunting season and generally support the notion that more accidents occur when there are more hunters. Specifically, the probabilities of related and unrelated accidents increase on the first and second Saturday of the hunting season, the first day of hunting season, and the first day of doe-only season and fall across days of the season. Besides the coefficients associated with the first Saturday of the season, we cannot reject that the corresponding coefficients in the related and unrelated accident regressions are equal for this set of regressors. We conjecture that on the first Saturday of the season many inexperienced hunters who have not shot their firearm since last hunting season are out, and these hunters are more likely to have not adequately inspected their firearm to ensure that it is functioning properly. Not properly inspecting their firearm would lead to more unrelated accidents such as unintentional discharge and sports arm defective.

In terms of buck and doe harvests, the coefficient estimates suggest that greater harvests decrease the probability of a related accident and increase the probability of an unrelated accident.[22,23] In contrast, the probability of a related accident appears to increase while the probability of an unrelated accident appears to decrease with estimated deer population.

To test whether the antler restrictions have a larger effect on safety immediately after the regulation change, we in-

[22] While the harvests do provide a proxy of the number of shots fired, harvests are also significantly influenced by the weather conditions. For example, having snow on the ground allows hunters to not only more easily spot deer (increasing harvests) but also more easily distinguish between fellow hunters and deer. This would explain the negative coefficients on the harvest variables in the related accidents regression.

[23] The results do not change appreciably if we allow the effect of buck and doe harvests on accidents to vary depending on whether bucks or does can be harvested on the particular day.

teract the indicator variables involving the antler restrictions with a year 2002 indicator variable and a year 2003–2005 indicator variable. Because the fraction of bucks meeting the antler requirements is smaller in 2002 than after 2002, we would expect, in terms of the related accident regression, larger negative coefficients when the antler restriction variables are interacted with the year 2002 indicator variable. As model 2 in table 3 indicates, these coefficient estimates are not only negative and statistically significant, they are also much larger than the estimated effects for subsequent years. Moreover, they are also statistically different from their corresponding coefficients in the unrelated accident regression.

Finally, we consider whether the regulations have a larger effect on related accidents in more congested areas. To test this hypothesis, we add interactions of the congestion measure with the indicator variable for whether hunters can harvest both bucks and does as well as with the point requirement.[24] The estimates of this specification (model 3 in table 3) show the effect of allowing bucks and does to be harvested on *related* accidents, due to hunters taking less care to distinguish a fellow hunter from a deer, is greater in areas more densely populated with hunters. However, the results in model 3 also suggest that the effects of changing the antler requirement on related and unrelated accidents do not vary with congestion.

V. Conclusion

This paper finds evidence that Pennsylvania hunting laws designed to control the population of deer had an unintended effect on safety. Changing the types of deer that can be legally harvested may affect hunter safety by altering the care a hunter takes in firing his rifle, hunter congestion, and the composition of hunters. To disentangle these effects, we control for hunter congestion and then separately consider accidents related to the care hunters take in distinguishing a fellow hunter from a deer (related accidents) and accidents that occur for other reasons (unrelated accidents). While related accidents are likely to be affected by both the care a hunter takes in firing his rifle and the composition of hunters, unrelated accidents are likely to only be affected by composition.

The differential effect of these law changes on related and unrelated accidents provides compelling evidence that hunting regulations affect the care hunters take when firing their rifles in a manner consistent with moral hazard. Specifically, we find that relaxing regulations to allow hunters to harvest both bucks and does reduces the care hunters take when firing a rifle, and requiring minimum antler standards increases the care hunters take when firing a rifle. In other words, we find a positive externality associated with these regulations.

[24] The bivariate probit model does not converge if we include interactions between our congestion measure and the individual antler restriction indicator variables.

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