EFFECTS OF HUNTING ACTIVITIES ON DEER VEHICLE COLLISIONS

by

Yunhe Ma

A thesis submitted to the faculty of
the University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Economics

Charlotte

2018

Approved by:

____

Dr. Craig A. Depken, II

____

Dr. John Gandar

____

Dr. Rob Roy McGregor

ABSTRACT

YUNHE MA. Effects of Hunting Activities on Deer Vehicle Collisions. (Under the direction of DR. CRAIG A. DEPKEN, II)

Deer-related vehicle crashes are a serious traffic safety hazard in the state of North Carolina, and number of DVCs spikes during hunting seasons. This paper provides an econometric analysis of the relationship between hunting activities and deer-related vehicle crashes during hunting season from year 2009 to 2016. Increases in the deer harvest increases the frequency of DVCs during hunting season. The buck population has a bigger impact on DVCs than the doe population. Harvesting deer on private lands has a smaller effect on DVC than harvesting on public hunting lands.

ACKNOWLEDGEMENTS

I would like to express my very great appreciation to Dr. Craig Depken for his patient guidance throughout this project.

Special thanks to my parents who always support me. And to Tan, who always believed in me and helped me went through difficult times during this project.

Table of Contents

CHAPTER 1: INTRODUCTION ... 1
CHAPTER 2: LITERATURE REVIEW ... 4
CHAPTER 3: DATA AND MODEL ... 8
3.1 Data Source ... 8
3.2 DVC quarterly data ... 9
3.3 Deer population estimate ... 9
3.4 Type of deer harvest ... 11
3.5 Location of deer harvest ... 12
3.6 Type of weapon used ... 14
3.7 General economic indicator ... 14
3.8 Descriptive statistics ... 15
3.9 Model Specification ... 15
CHAPTER 4: RESULTS AND INTERPRETATION ... 17
4.1 Selection of model ... 17
4.1.1 OLS vs. Fixed Effects ... 17
4.1.2 OLS vs. Random Effects ... 17
4.1.3 Fixed Effects vs. Random Effects ... 18
4.1.4 Equal Effects Tests ... 18
4.2 Number of DVCs During non-hunting season ... 18
4.3 Deer population estimator ... 19
4.4 Type of deer harvest ... 19
4.5 Type of weapon used ... 20
4.6 Location of harvest ... 20
4.7 Economic indicator ... 20
CHAPTER 5: CONCLUSION AND DISCUSSION ... 22
REFERENCES ... 25
APPENDIX A: SUPPLEMENTAL TABLES ... 27
APPENDIX B: FIGURES ... 34

CHAPTER 1: INTRODUCTION

Hunting is a popular activity in American culture, as it combines sportsmanship, adventure, survivalism, and marksmanship. Among game available for hunting, white-tailed deer, (Odocoileus virginianus, referred to as "deer" in this paper) is the most widely hunted game in many states as they can be found in all continental states. A large huntable deer population brings utility to hunters who track them, but also causes trouble as well from ruined backyards to fatal accidents. The risk of deer hunting is generally well recognized, as rifle-misfire, bullets that fly in the wrong direction, falling from tree-stands, and other hunting-related accidents can cause serious personal injury, sometimes with fatal consequences: in North Carolina, 45 people died in hunting-related accidents between 1990-2000, and 49 between 2000-2010. (NCDOT, 2018) Another category of accidents related to deer is even more troublesome: deer-related vehicle collisions (DVCs). This paper will study the relationship between certain deer hunting activities and the frequency of DVCs.

In year 2009, there were 17,901 DVCs in North Carolina. In year 2016, there were 18,205 DVCs. In other words, there are on average 50 DVCs per day in North Carolina, or one DVC every two days per county. DVCs also caused substantial property damage: in 2016, DVCs caused over $100 million in property damage. Because of the damage deer cause, traffic agencies have taken preventive actions, including setting fences and warning signs, and setting up driver awareness programs. Not all of those precautions are effective, or supported by researches, but according to wildlife agencies. The frequency of DVCs drops after some precautions are taken.

An important reason why deer cause so much trouble, also the reason why deer are the most popular games in the United States, is the abundance of the deer population. According to the North Carolina Wildlife Service, approximately 1 million deer live in the state of North Carolina. While the herd size is too large to be estimated precisely, the harvest data is carefully recorded in each hunting season, as required by law. In the 2009-2010 hunting season (deer hunting season usually starts in mid-September and ends in late-January), there were 169,273 bucks and does harvested on both game lands and other lands; and in the 2017-2018 hunting season, 161,854 bucks and does were harvested (NCWRC, 2018). While the harvest numbers appear to be a large, North Carolina is not even in the top ten states ranked by the number of deer harvested per year. In 2016-2017 hunting season, there were 2,991,587 deer harvested nationwide, one tenth of the estimated total deer population of 30,000,000 (Deerbusters, 2018).

DVCs have drawn attention from researchers since the 1960s, and most of those researches focused on patterns of DVCs and the effectiveness of existing preventive measures. Previous research studies how the surrounding environment (forest, crop field, residential area etc.), time of year, time of day, speed limit, traffic, fences, and other factors affect the likelihood of DVCs. Hunting activity, however, did not draw much attention from researchers until very recently. There are several studies done on hunting activity’s impact on deer herd patterns, showing a statistically significant relationship between deer hunting activities and the frequency of DVCs. Combined with the fact that hunting reduces the deer population, it is reasonable to assume that hunting activity would impact DVCs. This paper uses deer-hunting activity data obtained from NC Wildlife Commission, DVC data obtained from North Carolina Department of Motor Vehicles (NC DMV), and general population data from the Federal Reserve to examine this assumption.

CHAPTER 2: LITERATURE REVIEW

Although the first DVC may have occurred shortly after the invention of the automobile, there were very few studies on this issue until the late 1960s, when the number of DVCs increased rapidly and became a major traffic safety concern. In Pennsylvania, the number of DVCs increased by 218% between 1960 and 1967. In Michigan, the number also increased rapidly during the same period (Ross, 1976). Ross and Dale believed it was due to the substantial increase of both deer population and traffic volume. In addition, it can be argued that there was another reason behind the sharp increase of DVCs in mid-20th century: questionable effectiveness or even absence of preventive measures.

DVC preventive measures focus on how to prevent the deer herd from entering roads and how to keep drivers alerted when deer are about to cross the road. Most commonly used methods include fencing, overpasses and underpasses, reflectors, deer signs, ultrasonic warning whistles, lower speed limits, mirrors, and public awareness programs. Romin and Bissonette (1996) research on the application status, and effectiveness of DVC preventive measures. They distributed questionnaires to all 50 state natural resource agencies to inquire about the effectiveness of preventive measures and those agencies' opinions on how to prevent DVCs; 43 of them responded. Deer crossing signs were the most common measure, as 40 of 43 responding states applied them. Public awareness programs, ultrasonic warning whistles and reflectors were widely applied as well, both had around 20 states using them. However, none of those four commonly used measures were believed by the natural resource agencies to be effective. According to their opinion, deer-proof fencing was the most effect measure; 91% of agencies believe on its effectiveness versus 9% that did not believe. Underpasses or overpasses were the second most effect measure with 63% of agencies believed its effectiveness, 12% did not believe, and 25% voted for inconclusive. Those two measures, however, are not commonly used. None of the other measures had a believed successful rate above 35%. It shall be made aware of that none of the opinions above was directly supported by concrete data in this research.

There were several studies done in 1990s and early 2000s using statistical approaches to examine DVC preventive measure effectiveness. A study done in 2003 by James H. Hedlund, Paul D. Curtis, Gwen Curtis and Allan F. Williams, reviewed previous published studies and data they obtained from other sources directly related to DVCs. They put all measures into two categories: those that affected driver behaviors which included general education, signs, deer visibility, and speed limits, and those that affected deer behaviors which included fencing, underpasses and overpasses, at-grade crosswalks, reflectors, flagging, whistles, repellents, intercept feeding, and salt alternatives. Not all of these measures had a study done on them; and among those that were studied, only two of them were founded to be effective, which were the same ones approved by natural resources agencies: fencing and over/underpasses. Fencing has been found to statistically significantly decreases the frequency of DVCs in several separately conducted studies. Fencing shall be set as tall as 2.4m to prevent jumping, and be extended far enough along a roadway to prevent detouring. Once fencing is properly designed and set, DVCs can be reduced by as much as 80%. Underpass and overpass' effectiveness was not directly studied using a statistical method, however one study showed that the percentage of deer herd choosing to use underpasses and/or overpasses increases steadily after they are built: it raised to 85% in four years after the passes are built. Other measures were either not proven to be statistical significant, or had conflicting conclusions.

The potential effect of deer-hunting activities was mentioned in several papers, but was not thoroughly studied until about a decade ago. A state-level research was conducted by Krishnan Sudharsan, Shawn J. Riley and Scott R. Winterstein on the relationship between autumn hunting season and the frequency of deer-vehicle collisions in Michigan (Krishnan, etc. 2006). They compared frequency of night-time DVCs occurring 7 days, 14 days, and 28 days before and after the opening of firearm-hunting season. Both the 14 days and 28 days comparisons gave statistically significant result, showing that 14 days and 28 days after the opening of firearm-hunting season the frequency of DVCs decreased compared to before. The 7 days comparison did not yield statistically significant results. They believed the primary reason for this decrease was elimination of deer herd population during first month of firearm-hunting season.

Although the decrease of the deer population is a major and obvious effect of deer-hunting activities on the deer herd, hunting does more than that. Deer-hunting activities change the behavior patterns of the deer herd as well. A study from 1998 by John C, Kilgo, Ronald F. Labisky and Duane E. Fritzen, suggests that hunting activities drive the deer herd away from roads to avoid human activity. It is safe to presume that as the deer herd move away from roads, the frequency of DVCs should decrease as well.

However, Root, Fritzell and Giessman's research (1988) finds that intensive deer-hunting activities would increase the area of activity of does. Larger movement areas may lead to more DVCs. Bucks, on the other hand, did not alter movement patterns in response to intensive hunting.

CHAPTER 3: DATA AND MODEL

3.1 Date source

The data analyzed in this paper were obtained from three agencies. DVC data was obtained from the North Carolina Department of Transportation (NCDOT), deer harvest data is obtained from the North Carolina Wildlife Resources Commission (NCWRC), and economic indicator data was obtained from the Federal Reserve Bank of St. Louis website. The data cover years from 2009 to 2016, 8 years in total.

NCDOT publishes DVC data annually in the form of maps, one for each county per year. The number of DVCs per quarter can be found on those maps. NCDOT have more detailed DVC data, recording characteristics of every crash such as location and severity. However, the date of an accident is not included until 2014. Therefore, county level quarterly DVC data was used for this study.

NCWRC publishes deer harvest data annually (after each hunting season) in the form of detailed reports, which contain multiple data sets. Due to the size of the deer harvest per year, NCWRC does not publish detailed information by each harvest. A lot of these data sets are at county level. These county-specific deer harvest data categorize the number of harvests by type of deer, type of weapon used, and location.

Population and GDP data of each county can be easily extracted from FRED Economic Data Sets, and they are annual data.

3.2 DVC quarterly data

To study the effect of deer-hunting activities, DVC quarterly data are organized into 2 categories: hunting-season quarters DVC data and non-hunting-season quarters DVC data. Deer hunting season generally starts in early-September and ends in the first day of the next year. Therefore, the first two quarters of a year are labeled as non-hunting season quarters, and the rest are labeled as hunting season quarters. Number of hunting season DVCs is the dependent variable in the model.

The use of quarterly data is not ideal. Deer hunting season does not start until September, while the third quarter starts in June. Some of the DVCs labeled as hunting season DVCs occur before the hunting season starts. In addition, the hunting season calendar varies from region to region. In North Carolina, there are five hunting regions: Western, Northwestern, Central, Northwestern, and Southeastern. Each of them have a unique hunting season calendar. The chart below is 2018 hunting season calendar is shown. All of them starts in September 8 and ends on January 1, except for years when January 1 is on a Sunday. In North Carolina, hunting is prohibited on Sundays. The start dates of black powder seasons and gun seasons vary from region to region. Table 1 is the calendar of 2018-19 hunting season.

3.3 Deer population estimate

Deer population is arguably the most obvious and influential variable that may affect the frequency of DVCs. However, this variable is very difficult to estimate accurately. There are mainly two approaches to estimate deer population in a large area:

field measurement and deer harvest estimation. Field measurement can be executed through several devices: stationary trial camera, ground counting on automobiles, and helicopter counting. The idea is to measure deer population in a small area, then use the observation to estimate total local deer population. This approach has been adopted by wildlife agencies from time to time, but rarely on a consistent basis for to two reasons: 1) Filed measurement can be costly, and 2) High level of accuracy is not usually needed for deer population estimation. Trial cameras are stationary and relatively cheap, but they cover spots on predicted deer trials rather than covering the whole area. When placed in the wrong locations, they may give very misleading results. Observing with automobiles and helicopters can cover a larger area and are more likely to give accurate results, but they are more expensive. Even if the number of deer is measured very close to the true population, how to use it to estimate total local deer population accurately is still an unsolved question. To estimate total deer population with observations from small areas, many assessments and assumptions must be made, including disappearance(decay) rate, defecation rate, validity, and position of deer herds. In the end, the estimation of total deer population can only be expected to be "reasonable" at best.

A more commonly used method is estimation through harvest data. This method uses deer harvest data of a certain area to estimate deer population of the area. The most obvious weak point of this method is that it requires regular hunting activities. If hunting is limited or prohibited, this method cannot be applied. Even if an area has regular hunting activities, and deer population does have proportional relationship with deer harvest, there is still one problem: the ratio between deer harvest and deer population could only be roughly estimated. There is no study done in North Carolina establishing the precise numerical relationship between deer population and deer harvest data.

The idea behind the harvest estimation method, however, can be accepted and applied to a qualitative research like this one. It assumes that the deer population and the deer harvest have a proportional relationship. With this assumption, deer harvest data can substitute for deer population data to explore whether deer population changes have any effect on DVCs. To study the quantitative relationship between deer population and DVCs, accurate deer population data are required. In North Carolina, harvest estimation method is adopted by NCWRC to estimate county deer population density. This paper will use harvest estimation approach to estimate deer population.

3.4 Type of deer harvest

To most hunters, bucks are the most preferred deer to hunt because of their antlers. Harvesting a set of whitetail deer antler with 2 digits of points is not only the reason why many hunters start to hunt deer, it's also the reason why many hunters keep going into the field year after year. Does on the other hand, are less attractive. Some hunters hunt doe simply because they enjoy the sport, others hunt doe for meat. That is why in most cases, the buck harvest exceeds the doe harvest. State wildlife agencies tend to have different preferences. As mentioned in section 1, an overabundance of white-tailed deer is a serious problem in many states. Wildlife agencies seek methods to control deer population. As growth rates of the deer population are primarily dependent on female rates, many wildlife agencies promote doe hunting

Controlling the future deer population is likely to influence the frequency of DVCs as well, but how the type of deer being harvested affects the frequency of DVCs in the current hunting season is another story. Different types of deer harvest are expected to have different, or even opposite effects, on the frequency of DVCs. Previous studies have shown that bucks and does have their own behavior patterns, and react differently to hunting activities. Both bucks and does tend to migrate away from human residents and roads under hunting pressure, while does increase their activity range at the same time. Since deer harvest is used as the estimator for deer population, the harvest is not expected to have a negative effect on the frequency of DVCs. But because of does' unique reaction of hunting activities, it is still possible for the doe harvest to have negative effect.

County level harvest data from NCWRC has three categories of deer: antler buck (adult buck), button buck (young buck), and doe. Button buck is a small portion of the total harvest count at both country and state level. The antler buck harvest is larger than the doe harvest at the state level every year in the period between 2009 and 2017, but varies at the county level. The number of antler buck harvest and button buck harvest are combined since the button buck do not show any unique reactions to hunting activities different from antler buck.

3.5 Location of deer harvest

There are two types of hunting areas for deer: game lands (public hunting areas) and private lands. Although sometimes referred to as "public places" by hunters, game lands are not all owned by state or federal governments. Many of them are state-owned lands such as areas in national forests and national parks; some of them, however, are private-owned. They are called "public places" because these lands are managed by state wild life agencies and are open to the public. This means any hunter can visit these lands and hunt game providing they have the proper licenses, equipment, and respect of state and local hunting regulations. In North Carolina, game lands are managed by the North Carolina Wildlife Resources Commission.

Private lands are areas that are owned by individuals, not banned from hunting by law and/or regulation, and which require the owner's permission to enter and hunt. They can be edges of farmland, forests, meadows, or any other common non-residential areas. Private lands comprise most of the hunting areas, and the majority of the deer harvest occurs on private lands. Private lands have several advantages over public lands: 1) There is much less competition and disturbance on private lands, which means deer will not be harvested, or more commonly and annoyingly, scared off by fellow hunters, and 2) Because there is less disturbance, deer herds on private land are less alerted and have more constant patterns. Constant patterns are particularly important to North America deer hunters because the majority of hunters use a stationary hunting method rather than an active method. Hunters find a spot where deer herds are expected to pass through, set up camouflage tents, platforms, or tree stands, wait for the deer herd to arrive and ambush them. Hunters on private land can set up and use permanent ambush spots.

Deer herds on public lands are usually more disturbed during hunting season than those on private lands. Therefore, in counties with more game lands, the harvest may be having more hunting activity related DVCs than counties that have little game lands harvest, holding other factors constant. Deer harvest data sets from NCWRC contains numbers of harvest on game lands and private lands in each county. Number of harvest on private lands will be included in the model.

3.6 Type of weapon used

Four types of weapons are most commonly used in deer hunting: bows, crossbows, black powder firearms, and modern firearms. Bows and crossbows can be used in archery season, which starts in September and covers the whole hunting season. Black powder season opens second, and modern firearm season opens last. Modern firearms generally include rifles and shotguns. Although they are more efficient in harvesting deer, black powder firearms and modern firearms make much more noise than archery weapons, which would cause greater disturbance to deer herds. In some previous studies, the definition of “deer hunting season” as a study subject does not include archery or black powder season. Therefore, in the same county, hunting seasons that have a larger firearm harvest may see more DVCs than hunting seasons that have a larger archery harvest, holding other factors constant including total harvest count.

3.7 General economic indicators

County population and income are included in the model as well. More residents and higher GDP per capital generally leads to more intensive human activity. More residents and higher income usually generate higher traffic volume. However, human activity could also scare deer herds away from road. No studies have been done on the effect of population or income level on DVCs.

3.8 Descriptive statistics

As been shown in table 4, the mean of dvc_hs is larger than the mean of dvc_nhs, suggesting that DVCs are more likely to occur during deer hunting seasons. The mean of doe_hvst is around the half of the mean of deer-pop, showing that the number of buck harvest and doe harvest is close. The mean of fa_hvst and pri_land is very close to the mean of deer_pop, which means the majority of the harvests are firearm harvests, and most of them are on private lands.

For all variables, between standard deviations and overall standard deviations are very close. Within standard deviations, however, is much smaller than between standard deviations, which suggests that most of the variable is between counties rather than within counties. As been shown in figure 1, counties with high frequency of DVCs can have as many as 800 DVCs during hunting seasons, while some counties do not have more than 5 DVCs.

Aggregate number of DVCs across all counties by quarter-year (figure 2) shows a clear pattern. Year dummy is added to counter this pattern. Number of DVCs in 2015 was significantly lower than 2014 and 2016, a possible reason behind this drop is the draught of 2015, which might cut the food source of deer herd.

3.9 Model Specification

This paper uses a multiple linear regression model as follows:

$$dvc\_hs_{it} \ = \ B_0 + B_1 dvc\_nhs_{it} + B_2 deer\_pop_{it} + B_3 doe\_hvst_{it} + B_4 fa\_hvst_{it} + B_5 pri\_land_{it} + B_6 cnty\_pop_{it} + B_7 cnty\_inc_{it} + e_{it} + \alpha_i$$

The B_i are parameters to be estimated, α_i are county fixed effects, and ε_{it} is an error term. This model contains only continuous numerical variables. To avoid potential collinearity problem, the number of non-firearm harvest and number of harvest on public land are not included in the model. Table 3 is a list of all variables.

CHAPTER 4: RESULTS AND INTERPRETATION

4.1 Selection of model

Four models were tested, and the parameters are shown in table 1. All of them have statistically significant parameters. Further tests are performed to select the best model.

4.1.1 OLS vs. Fixed Effects

The F- test is used to compare the pooled OLS effects model and the fixed effects model. The null hypothesis is that all the fixed effect intercepts are zero. If these intercepts are zero, then the fixed effects model is no reliable. Table 2 shows that the F-test gives a p-value of 0.0000, thus the null hypothesis is rejected, and the fixed effects model is superior to the OLS model. See table 5.

4.1.2 OLS vs. Random Effects

The Breusch and Pagan Lagrangian multiplier test is picked to compare the two models. The null hypothesis of this test is that the variance of the random effect is zero. Table 3 shows that the p-value of 0.0000, thus the null hypothesis is rejected, and the random effects model should be picked over the OLS model. See table 6.

4.1.3 Fixed Effects vs. Random Effects

The Hausman test is used to compare the fixed effects model and the random effects model. The null hypothesis is that the coefficients from two models are consistent. If they are consistent, then random effects can be accepted. Table 4 shows a p-value of 0.0000, thus the null hypothesis is rejected, and fixed effects model is preferred than the random effects model. See table 7.

4.1.4 Equal Effects Test

The Mundlak model is used to compare the between effects model, the fixed effects model, and the random effects model. The first joint test compares all the mean effects to the within effects, and the null hypothesis is that there is no difference. Table 5 shows that the p-value is 0.0000, thus the null hypothesis is rejected. The random effects model is dropped at this point. The second joint test is to test the mean values, and the null hypothesis is that the mean values are jointly zero. Table 6 shows that the p-value equals to 0.0000, thus the null hypothesis is rejected and both the between effects model and the within (fixed) effects model will be used in this study. See table 8 and 9.

4.2 Number of DVCs during non-hunting season

Both the fixed effects model and between effects model prove that DVCs during non-hunting season (dvc_nhs) and DVCs during hunting season (dvc_hs) have a strong positive relationship. The coefficient is 0.816 using fixed effects model, and 1.534 using between effects model, both greater than 0.5, fits the expectation that frequency of DVCs increases during hunting season.

4.3 Deer population estimator

Under the fixed effects model, total deer harvest as an estimator of deer population has a strong positive effect on the number of DVCs during hunting season, assuming deer population and total deer harvest are proportionally correlated. Every 100 increase of total deer harvest indicates a 15 increase in DVCs during hunting season using the fixed effects model.

The between effects model, does not project a statistically significant coefficient for deer population, with a t-statistic of 1.73.

4.4 Type of deer harvest

When using the fixed effects model, variable doe_hvst has a negative coefficient which is statistically significant. The coefficient is -0.053.

The t-statistic of doe_hvst under the between effects model is 1.32, not statistically significant either.

4.5 Type of weapon used

The Type of weapon used does not seem to affect the frequency of DVCs during the hunting season using the fixed effects model. The coefficient only has a t-value of 0.09.

The between effects model, however, indicates that the two variables have a strong negative relationship. This results conflicts with the hypothesis that more modern firearm kills disturb the deer herd, thus leading to more DVCs. One possible explanation is that in counties that have more rifle hunting than bow hunting, deer herds have more stable patterns running away from rifle sounds rather than flee towards possibly dangerous directions, such as roads.

4.6 Location of harvest

Just like the doe harvest, the deer harvest on private land has a negative but smaller effect on frequency of DVCs during hunting season compared to the deer harvest on public land using the fixed effects model. It has a coefficient of -0.101. This result fits the hypothesis as well. Location of harvest also does not seem to affect DVCs using between effects value, with a t-statistic of only 0.21.

4.7 Economic indicator

Under the fixed effects model, the county population has a strong negative relationship with number of DVCs during hunting season, and the coefficient is -0.0006.

For every 10,000 increases in population, the number of DVCs during hunting season decreases by 6. This result may indicate that the hypothesis that more intensive human activity could scare deer herds away from human settlements may be correct. County income does not have a statistically significant coefficient. The between effects model does not give statistically significant results.

CHAPTER 5: CONCLUSION AND DISCUSSION

This study explores the effects of certain aspects of hunting activities and other factors on frequency of DVCs during hunting season. Several factors are proven to be statistically significant, which include total deer harvest, type of harvest, type of weapon used, location of harvest, and county population.

In this study, the total deer harvest is used as an estimator of deer population. This estimation approach is accepted by several wildlife agencies including North Carolina Wildlife Resources Commission. Assuming deer harvest and deer population are perfectly correlated, this study proves that deer population has a strong positive relationship with frequency of DVCs during hunting season both between counties and within the same county.

The doe harvest was endorsed by many state wildlife agencies as an active method of deer population control. The idea is to reduce reproduction. This study proves that deer harvest, compared to buck harvest, does not only cut reproduction of deer herd which would reduce frequency of DVCs in the future, it would reduce DVCs in current season as well. A possible explanation for this result is as Root's study in 1988 pointed out, does react to hunting activities by increasing their movement area. This pattern change may lead to less DVCs combined with Kilgo's study that proves doe herds tend to move away from roads when facing intensive hunting activities. However, the doe harvest shows weaker statistically significance in the between county comparison. This may prove Root and Kilgo's hypothesis as well: in counties that have more doe harvest, does tend to have more stable patterns evading hunting activities and apply negative effect on the frequency of DVCs, which is strong enough to offset the positive effect of population increase.

A more interesting finding of this study is that location of deer harvest and type of weapon used play significant roles in the frequency of DVCs. No previous studies have looked into these two factors. The deer harvest on private land has a significant smaller effect on frequency of DVCs than deer harvest on public land in both within comparisons. As been discussed in chapter 3, it is likely due to less disturbance caused by harvesting deer on private land. On private lands, fewer hunters are present and both parties (deer and hunters) are familiar with each other, consequently the deer herd would not be driven to roads due to unexpected threats as often as those that live on public hunting areas. The deer herds on private lands may develop cleverer patterns and hides deeper into the woods during hunting seasons. This can also explain why firearm has a negative effect on the frequency of DVCs when compare between counties, while has no clear effect when compare within a county.

While these findings are very encouraging, several improvements can be made in future. The deer population is one of the most crucial factors which may potentially affects frequency of DVCs as well as deer harvest. This paper adapts the approach used by the NC Wildlife Resources Commission, which assumes deer harvest and deer population are perfectly correlated. This estimation approach, while being very helpful for hunting purpose, is not reliable enough for research. It is picked because no accurate NC deer census can be found at present. Conventional deer census methods are costly and time consuming. Recent development of drone and monitoring/identification technology have great potential in deer census. Once successfully applied, deer population could be gathered with high level of accuracy. With accurate deer population data, the relationship between deer population and deer harvest can be studied on a large geographical scale, and it would be possible to explore the effects of deer harvest and deer population on DVCs separately.

REFERENCES

Allen, Ross E. and Dale R. McCullough. (1976). Deer-Car Accidents in Southern Michigan. The Journal of Wildlife Management. 40(2): 317-325.

Batcheler, C. L. (1975). Development of a Distance Method for Deer Census from Pellet Groups. The Journal of Wildlife Management. 39(4): 641-652.

Deerbusters.com

Federal Reserve Economic Data: FRED. Federal Reserve Bank of St. Louis. research.stlouisfed.org/fred2/.

Hansen, Lonnie and Jeff Beringer. (1997). Managed Hunts to Control White-Tailed Deer Populations on Urban Public Areas in Missouri. Wildlife Society Bulletin. 25(2): 484-487.

Hedlund, James H., Paul D. Curtis, Gwen Curtis, Allan F. Williams. (2003). Methods to Reduce Traffic Crashes Involving Deer: What Works and What Does Not. Insurance Institute for Highway Safety.

Kilgo, John C., Ronald F. Labisky and Duane E. Fritzen. (1998). Influences of Hunting on the Behavior of White-Tailed Deer: Implications for Conservation of the Florida Panther. Society for Conservation Biology. 12(6): 1359-1364.

Labisky, Ronald F., Margaret C. Boulay, Karl E. Miller, Robert A. Sargent, Jr. and Jodie M. Zultowsky. (1995). Population Ecology of White-Tailed Deer in Big Cypress National Preserve and Everglades National Park. Department of Wildlife Ecology and Conservation, University of Florida.

North Carolina Deer Harvest Data. North Carolina Wildlife Resources Commission. ncwildlife.org/Hunting/Seasons-Limits/Harvest-Statistics/White-tailed-Deer-Harvest-Reports.

North Carolina DVC Data. North Carolina Department of Transportation. connect.ncdot.gov/resources/safety/pages/crash-data.aspx

Riley, Shawn J., Daniel J. Dechker, Jody W. Enck, Paul D. Curtis, T. Bruce Lauber and Tommy L. Brown. (2003). Deer populations up, hunter populations down: Implications of interdependence of deer and hunter population dynamics on management. Ecoscience. 10(4): 455-461.

Romin, Laura A. and John A. Bissonette. (1996). Deer: Vehicle Collisions: Status of State Monitoring Activities and Mitigation Efforts. Wildlife Society Bulletin. 24(2): 276-283.

Root, Brian G., Erik K. Fritzell and Norbert F. Giessman. (1988). Effects of Intensive Hunting on White-Tailed Deer Movement. Wildlife Society Bulletin. 16(2): 145-151.

Shult, Milo J. and Bill Armstrong. (1999). Deer Census Techniques. Texas Park and Wildlife.

Sundharsan, Krishnan, Shawn J. Riley and Scott R. Winterstein. (2006). Relationship of Autumn Hunting Season to the Frequency of Deer-Vehicle Collisions in Michigan. The Journal of Wildlife Management. 70(4): 1161-1164.

APPENDIX A: SUPPLEMENTAL TABLES

Table 1: 2018-19 hunting season calender

Region	Archery season	Black powder season	Gun season
Western	Sept. 8-30, 2018 October 14-18, 2018 Dec. 9, 2018-Jan. 1, 2019 (antler buck only)	Oct. 1-13, 2018	Nov. 19-Dec. 8, 2018
Northwestern	Sept. 8-Nov. 2, 2018	Nov. 3-16, 2018	Nov. 17, 2018-Jan.1, 2019
Central	Sept. 8-Oct. 26, 2018	Oct. 27-Nov. 9, 2018	Nov. 10, 2018-Jan. 1, 2019
Northwestern	Sept. 8-28, 2018	Sept. 29-Oct. 12, 2018	Oct. 13, 2018-Jan. 1, 2019
Southeastern	Sept. 8-28, 2018	Sept. 29-Oct. 12, 2018	Oct. 13, 2018-Jan. 1, 2019

Table 2: Coefficients from 4 models

Variables	OLS	Fixed Effects	Between Effects	Random Effects
dvc_nhs	1.434***	0.816***	1.534***	1.297***
deer_pop	0.065***	0.149**	0.049***	0.079**
doe_hvst	-0.00003	-0.053*	0.028	-0.027
fa_hvst	-0.064***	0.002	-0.070***	-0.046**
pri_land	-0.001	-0.101*	0.004	-0.016
cnty_pop	0.0001***	-0.0006***	0.00009	-0.0001***
cnty_inc	-0.0001	-0.0003	-0.00008	-0.0002
_cos	3.315	56.544*	-1.689	4.184

Table 3: List of all variables

	Variable description	Variable	Unit Type
Y	DVCs during hunting season	dvc_hs	Number
X_1	DVCs during non-hunting season	dvc_nhs	Number
X_2	Deer population estimator	deer_pop	Number
X_3	Number of doe harvest	doe_hvst	Number
X_4	Number of firearm harvest	fa_hvst	Number
X_5	Number of harvest on private land	pri_land	Number
X_6	County population	cnty_pop	Number
X_7	County income	cnty_inc	US Dollar

Table 4: Descriptive statistics

Variable		Mean	Std. Dev.	Min	Max	Observations	
dvc_hs	overall	121.5013	105.9187	0	769	N =	800
	between		102.9019	3.875	640.5	n =	100
	within		26.88377	-78.99875	275.7513	T =	8
dvc_nhs	overall	73.0325	61.74234	0	391	N =	800
	between		60.12283	1	339.25	n =	100
	within		15.13377	-81.2175	184.5325	T =	8
deer_pop	overall	1674.2	1061.906	50	6063	N =	800
	between		1033.835	63.125	5084.375	n =	100
	within		261.1371	484.075	2798.075	T =	8
doe_hvst	overall	743.6425	514.226	1	2848	N =	800
	between		499.2871	4.5	2382.75	n =	100
	within		131.6237	129.6425	1382.642	T =	8
fa_hvst	overall	1513.576	1013.061	45	5904	N =	800
	between		988.2044	57.375	4899	n =	100
	within		241.4557	385.7013	2518.576	T =	8
pri_land	overall	1615.376	1046.077	9	5980	N =	800
	between		1019.093	13.75	5000.625	n =	100
	within		254.6089	433.7513	2723.751	T =	8
cnty_pop	overall	97954.48	149839.5	4101	1054835	N =	800
	between		150292.8	4218.875	979501.4	n =	100
	within		7864.628	17496.1	180663.1	T =	8
cnty_inc	overall	33669.68	5856.696	22732	58438	N =	800
	between		5410.954	26067.63	52447.88	n =	100
	within		2297.602	25603.43	39865.68	T =	8

Table 5: OLS vs. fixed effects tests

```
Fixed-effects (within) regression               Number of obs     =        800
Group variable: county1                         Number of groups  =        100

R-sq:                                           Obs per group:
     within  = 0.4943                                         min =          8
     between = 0.0005                                         avg =        8.0
     overall = 0.0037                                         max =          8

                                                F(14,686)         =      47.90
corr(u_i, Xb)  = -0.6035                        Prob > F          =     0.0000
```

dvc_hs	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
dvc_nhs	.8156868	.0507026	16.09	0.000	.7161359	.9152376
deer_pop	.1485137	.0432244	3.44	0.001	.0636457	.2333817
doe_hvst	-.0528951	.0227304	-2.33	0.020	-.0975246	-.0082655
fa_hvst	.0018118	.0198416	0.09	0.927	-.0371459	.0407694
pri_land	-.1009204	.0405411	-2.49	0.013	-.18052	-.0213209
cnty_pop	-.0005691	.000106	-5.37	0.000	-.0007773	-.0003608
cnty_inc	.0003	.0008107	0.37	0.711	-.0012916	.0018917
year						
2010	8.537759	3.011015	2.84	0.005	2.625847	14.44967
2011	2.963003	3.109538	0.95	0.341	-3.142352	9.068357
2012	10.7567	3.730434	2.88	0.004	3.432265	18.08114
2013	4.419815	3.868262	1.14	0.254	-3.175239	12.01487
2014	-6.049017	4.557436	-1.33	0.185	-14.99721	2.89918
2015	.364701	5.430518	0.07	0.946	-10.29773	11.02713
2016	-4.984939	5.911529	-0.84	0.399	-16.5918	6.621924
_cons	56.54404	28.49735	1.98	0.048	.5915478	112.4965
sigma_u	130.97376					
sigma_e	20.631613					
rho	.97578677	(fraction of variance due to u_i)				

F test that all u_i=0: F(99, 686) = 5.83 Prob > F = 0.0000

Table 6: OLS vs. random effects test

```
Breusch and Pagan Lagrangian multiplier test for random effects

        dvc_hs[county1,t] = Xb + u[county1] + e[county1,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
                  dvc_hs |   11218.76       105.9187
                       e |   425.6635       20.63161
                       u |   122.8912       11.08563

        Test:   Var(u) = 0
                             chibar2(01) =    70.69
                          Prob > chibar2 =   0.0000
```

Table 7: The Hausman test

	(b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
dvc_nhs	.8156868	1.296959	-.4812727	.0390547
deer_pop	.1485137	.0797754	.0687383	.0355649
doe_hvst	-.0528951	-.0274658	-.0254292	.015374
fa_hvst	.0018118	-.0459262	.0477379	.0142857
pri_land	-.1009204	-.0155604	-.0853601	.0356131
cnty_pop	-.0005691	.0001423	-.0007113	.0001052
cnty_inc	.0003	-.0002236	.0005237	.0007639
year				
2010	8.537759	6.065425	2.472334	.
2011	2.963003	-2.019034	4.982037	.
2012	10.7567	8.531766	2.224938	1.404158
2013	4.419815	-.3840979	4.803913	1.572628
2014	-6.049017	-13.73293	7.68391	2.852714
2015	.364701	-4.016163	4.380864	3.933603
2016	-4.984939	-12.82344	7.838496	4.550499

Coefficients

```
                          b = consistent under Ho and Ha; obtained from xtreg
           B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(12) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                           =      213.49
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

Table 8: Equal effects test-1

```
 ( 1)  diff__dvc_nhs - mean__dvc_nhs = 0
 ( 2)  diff__deer_pop - mean__deer_pop = 0
 ( 3)  diff__doe_hvst - mean__doe_hvst = 0
 ( 4)  diff__fa_hvst - mean__fa_hvst = 0
 ( 5)  diff__pri_land - mean__pri_land = 0
 ( 6)  diff__cnty_inc - mean__cnty_inc = 0

           chi2(  6) =  210.52
         Prob > chi2 =    0.0000
```

Table 9: Equal effects test-2

```
 ( 1)  mean__dvc_nhs - mean__deer_pop = 0
 ( 2)  mean__dvc_nhs - mean__doe_hvst = 0
 ( 3)  mean__dvc_nhs - mean__fa_hvst = 0
 ( 4)  mean__dvc_nhs - mean__pri_land = 0
 ( 5)  mean__dvc_nhs - mean__cnty_inc = 0

           chi2(  5) = 2854.96
         Prob > chi2 =    0.0000
```

APPENDIX B: FIGURES

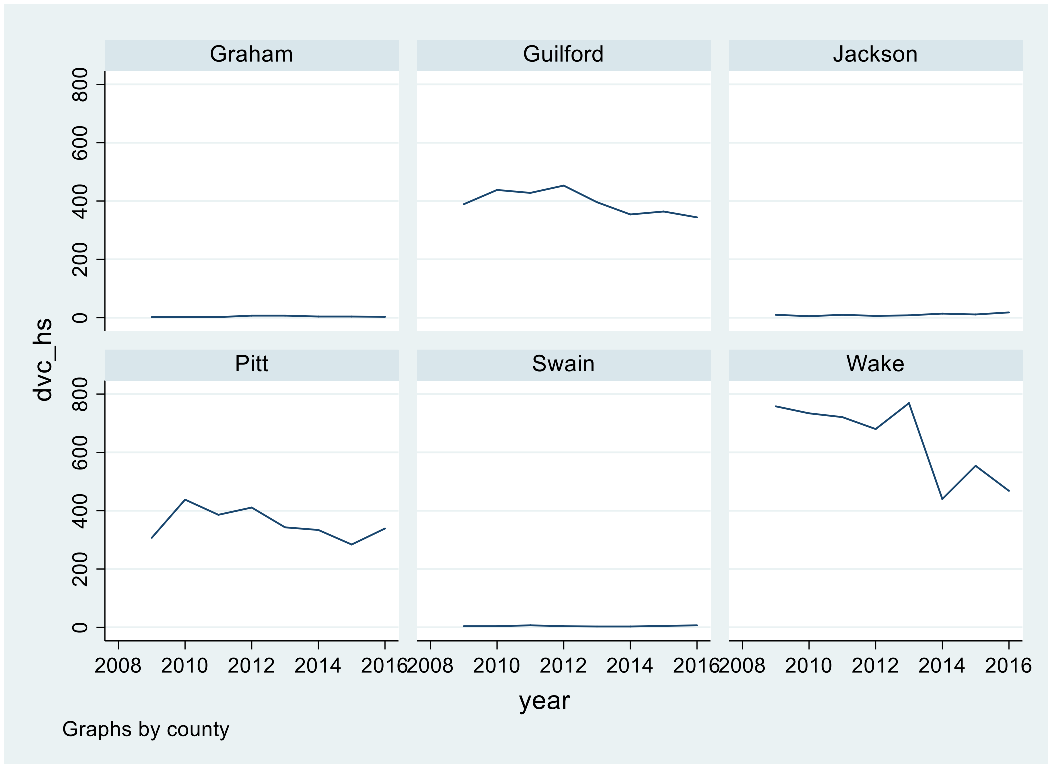

Figure 1: DVCs during hunting seasons from 6 counties

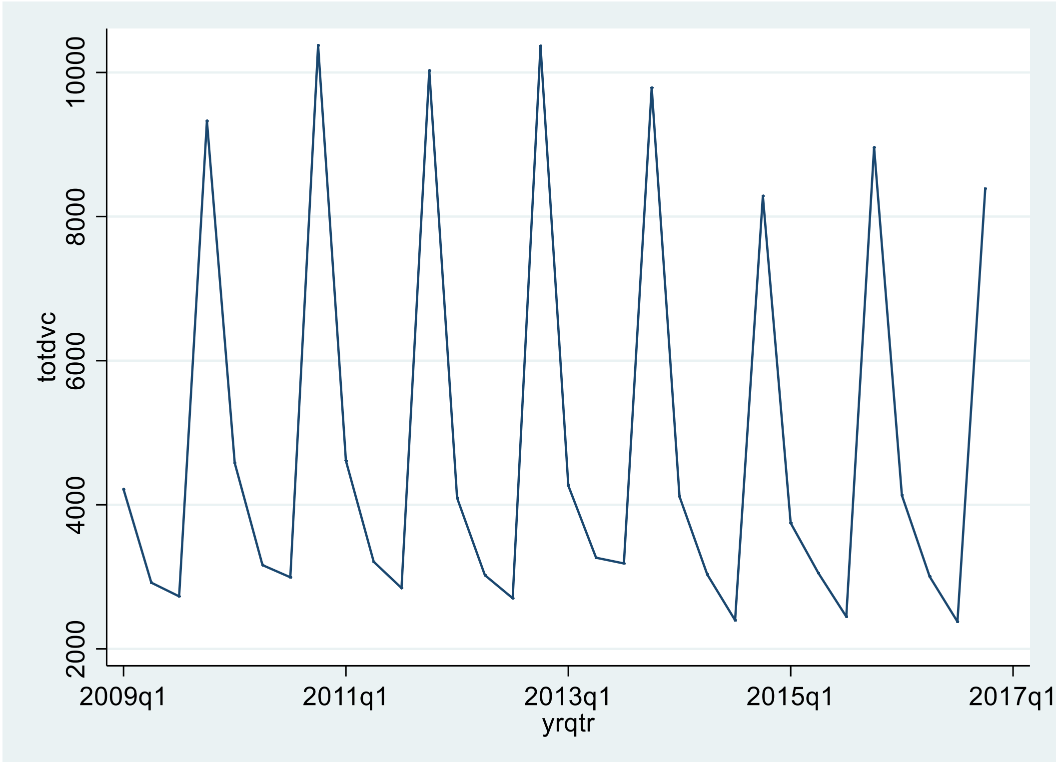

Figure 2: Aggregate number of DVCs across all counties by quarter-year