AN ANALYSIS OF DEER-VEHICLE COLLISIONS: THE CASE OF OHIO

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Abstract: The costs of deer-vehicle collisions (DVCs) in Ohio are estimated to be in excess of US$52 million annually. The intention of this paper is to identify factors contributing to the abundance of DVCs in Ohio, calculate the average cost of a deer-vehicle collision event, and illustrate the potential gains in economic efficiency from alternative approaches for reducing DVCs. Our results suggest that large potential economic gains from reducing DVCs in Ohio exist and that the optimal strategies for achieving these reductions seem to combine both changes in deer management schemes and deer-vehicle mitigation strategies.

Key words: bioeconomics, deer-vehicle collisions, Ohio, panel data, wildlife valuation

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In 1994, Ohio had nearly 26,000 reported deer-vehicle collisions (DVCs), increasing by nearly 60%, or at an annual rate of approximately 1,600 cases, since 1989. These trends are not surprising given the increases in both white-tailed deer (*Odocoileus virginianus* – deer, hereafter) populations and traffic volume. From 1989 to 1994, buck-gun harvest per square mile, which is defined as the number of bucks harvested during the 2-week shotgun season and has been shown to be highly correlated with deer population (Culbertson and Stoll 1990), increased by nearly 62%. Over this same 5-year period, the number of registered vehicles, which serves as a proxy for traffic volume, increased by roughly 20%. These trends, moreover, are not unique to Ohio. Cook and Daggett (1995) find that incidences of DVCs in a number of midwestern states have increased significantly over a recent 10-year period. Indeed, of Ohio's 5 contiguous states and Wisconsin, the average annual number of reported DVCs per state from 1989 to 1994 was approximately 23,000, with Kentucky and Michigan having the lowest and highest averages (4000 and 49,000, respectively) and Ohio falling in the middle with nearly 21,400 (Tonkovich 1995). Nationally, over 538,000 DVCs were reported in 1991 (Romin and Bissonette 1996a).

One need only acknowledge the estimated costs associated with these DVCs to understand why deer management goals, such as those purported by the Ohio Department of Natural Resources Division of Wildlife (ODNR), include managing deer populations with an eye on conflicts with motor travel. For instance, the Ohio Department of Public Safety (ODPS 1997), using the National Highway Traffic Safety Administration's average cost per accident by severity of accident, estimated that the costs associated with DVCs in 1996 exceeded US$52 million (in 1996 dollars, as all dollar estimates in the following will be indexed). Work by Decker et al. (1990) suggested that the reported 57,000 DVCs in New York in 1988 resulted in an estimated US$66.3 million in vehicle damage. Nationwide, Conover et al. (1995) estimated that DVCs cost approximately US$1.2 billion annually.

Yet while large deer populations may lead to more DVCs and other types of negative deer-human conflicts (e.g., crop damage), these populations also generate social benefits. That is, there are both consumptive and nonconsumptive values associated with deer. For instance, Loomis et al. (1989) estimated that total consumer surplus from deer hunting in California in 1987 was US$230 million whereas the consumer surplus from viewing deer was approximately US$43 million. In Ohio, hunters spent nearly US$15 million in 1997 on permits and licenses for the opportunity to hunt deer. Furthermore, Schwabe et al. (2001) estimated that Ohio hunters would have been willing to pay nearly US$1.4 million in 1996 for an additional day of deer hunting. Indeed, these numbers highlight another component of many states deer management goals – to maximize the recreational benefits associated with hunting, viewing, and photographing deer. From an economic perspective, then, deer management goals are essentially intended to achieve and maintain that population level where the differences between the benefits and costs – i.e., *net benefits* – are greatest.

The objectives of this research are to identify factors contributing to the abundance of deer-vehicle collisions in Ohio, calculate the average cost of a deer-vehicle collision event, and illustrate the potential gains in economic efficiency from alternative approaches for DVCs. Using data at both the county-level and the individual road-segment level from Ohio, we attempt to illustrate the extent to which deer-vehicle collisions are affected by deer population size, traffic volume, location, harvest quantities, and mitigation efforts. Using the regression results from 1 set of analyses, we then illustrate the potential biological and economic implications of 2 general strategies for reducing DVCs. While the focus of our exercise is on Ohio and a few selected counties within Ohio that differ with respect to deer populations, deer habitat, and number of vehicles, our general approach can be applied to any management unit for controlling deer populations.

RELATED LITERATURE

There are essentially 3 strands of literature associated with DVCs: the direct costs of DVCs, mitigation efforts for reducing DVCs, and the potential relationships between DVCs and deer population size. An equally important strand of literature is the environmental and natural resource economics literature related to optimal deer management. This latter strand, notably works by Keith and Lyon (1985) and Cooper (1993), employs a bioeconomic framework and evaluates optimal management strategies with consideration to biological and economic factors.

Direct Costs of DVCs

The direct costs associated with DVCs can be categorized into 2 main areas: vehicle accident costs and deer losses. Results in the literature associated with vehicle accident costs have varied quite dramatically. In a summary of vehicle-accident costs by Conover et al. (1995), the average vehicle repair bill varied between US$1,303 in Michigan (Hansen 1983) to nearly US$2,389 in Pennsylvania (Witmer and deCalesta 1992). Romin and Bissonette (1996a), in one of the most comprehensive studies of property damage from DVCs, used unpublished data from the Vermont Department of Transportation and estimated that the average cost per accident, given 10 years of data covering 24,884 DVCs, was US$2,103. A large part of the variation in the vehicle accident costs is likely due to differences in both methodology and definition. For instance, Reed et al. (1982) surveyed vehicle repair costs from Colorado State Patrol accident reports and benchmarked those against accident values as reported in claims to insurance companies. Alternatively, Hansen (1983) surveyed drivers who had submitted accident reports to the Michigan State Police to obtain cost estimates.

DVC literature incorporating the costs associated with human injury and fatalities are limited. This is due to both the difficulties associated with assigning costs to these events (Reed et. al. 1982), and the fact that the percentages of collisions resulting in human injury or fatality are quite low, approximately 4% (Stoll et al. 1985) and 0.029% (Rue 1989), respectively. Two studies that do acknowledge these components include Hansen (1983) and Romin and Bissonette (1996a). Hansen (1983) reports US$173 as the average cost associated with the morbidity and mortality effects of a DVC, including medical costs, lost wages, and the value of a statistical life. Romin and Bissonette (1996a) reported that approximately 120 people are killed annually due to DVCs. Using a value of life statistic of US$1.5 million that they cited from the Federal Highway Administration, the yearly cost associated with DVC-related human mortality is nearly US$180 million.

In addition to damages to vehicles and humans, DVCs often result in deer fatality. Of the collisions surveyed by Allen and McCullough (1976), deer fatalities occurred in approximately 92% of DVCs. Within the DVC-related literature, the value of a deer ranges from US$965 (Reed et al. 1982) to US$1,468 (Romin and Bissonette 1996a). Within the environmental and natural resource economics literature, values have been estimated at US$35 (Livengood 1983), US$64 (Keith and Lyon 1985), US$209 (Loomis et al. 1989), and US$182 (Schwabe et al. 2001). While these values all pertain to hunting values, they are estimated with different nonmarket valuation techniques, in different regions of the U.S., and for different species of deer.

For instance, Livengood (1983) uses a hedonic model and estimates the value of an additional whitetail deer for hunting in Texas. Keith and Lyon (1985) use a household production function approach and estimate the value of an additional mule deer for hunting in Utah. Loomis et al. (1993) used the contingent valuation method and estimated the value of a mule buck for hunting in California. Finally, Schwabe et al. (2001) used a random utility model to estimate the value of an additional whitetail deer for hunting in Ohio.

DVC Mitigation Strategies

There are numerous proposed, tried, and evaluated mitigation strategies to decrease DVCs, ranging from methods that aim to reduce deer appearance on highways to strategies that seek to increase human perception or the awareness of the human presence associated with DVCs (Primo and Primo 1996). With reference to the first category, strategies include, but are not limited to, different types of fencing (Halls et al. 1965, Falk et al. 1978, Feldhamer et al. 1986), underpass structures and overpass structures (Reed et al. 1975), reflectors (Reeves and Anderson 1993, Pafko and Kovach 1996, Ujvari et al. 1998), and intercept feeding (Wood and Wolfe 1988). Deer warning signs (Pojar et al. 1975) and deer whistles (Romin and Dalton 1992) are strategies that attempt to increase human perception or the awareness of human presence. Both Tonkovich (1995) and Romin and Bissonette (1996a) provide a detailed summary of these strategies.

The lack of adequate control of extraneous variables and poor study design in field experiments has compromised a great deal of the DVC research. For example, Tonkovich (1995) noted that many DVC studies involving reflectors, and in particular Swareflex reflectors, may have been plagued by either or both of these factors. Because annual fluctuations in deer numbers occur and are the result of a multitude of factors, it is essential that multiple years of data with adequate control for untreated sites be used. In this way, it should be possible to reduce the likelihood that the observed research findings are due to factors other than the treatment. Such factors, including population size, weather, habitat conditions, are likely to impact deer movement and DVCs and thus should be monitored.

DVCs and Deer Populations

Whether highway losses from DVCs are strictly additive, partially compensatory, or strictly compensatory may have important implications on long terms trends in deer population (Lehnert 1996). This, in turn, may have implications on harvest rates. Recent papers that shed some light on the relationship between DVCs and deer population are Sitar et al. (1998), and Lehnert et al. (1996). In their analysis of white-tailed deer in Michigan, Sitar et al. (1998) found that roadkill accounted for 11.1% and 7.1% of the nonmigratory and migratory deer mortality, respectively. Alternatively, research by Lehnert et al. (1996) of mule deer in Utah found that highway mortality removes between 5.6% and 17.4% of the population each year. Lehnert et al. then compared 3 simulation models that assumed highway losses are strictly additive, partially compensatory, or strictly compensatory to see which model best explained the observed behavior. Their results indicated that highway losses were partially compensatory, suggesting that deer mortality from DVCs was not completely offset by mortality arising from other factors (e.g., hunting, predation, starvation, etc.).

Optimal Deer Management

Following the seminal work by Brown and Hammack (1973) on wildlife-related recreational management, the use of bioeconomic modeling for optimal wildlife management exercises has been most prominent in the evaluations of alternative fishery management policies (McConnell and Sutinen 1979, Bockstael and McConnell 1981, Wilson 1982, Schuhmann and Easley 2000). Yet 2 studies that use bioeconomic models to evaluate optimal deer management include Keith and Lyon (1985) and Cooper (1993). As mentioned in Schuhmann and Schwabe (this issue), Keith and Lyon (1985) derived parameters that defined the relationships between a mule deer herd's population dynamics, hunter utility, and the marginal value of an additional deer. Using data on mule deer populations from Robinette et al. (1977) and assuming hunter harvest is proportional to herd size, they estimated that the value of an additional deer is US$64. Their model, though, did not distinguish between bucks, does, and fawns and they did not include the costs of maintaining the deer herd – an omission they noted is required to achieve the economically efficient herd size.

Alternatively, Cooper (1993) formulated a bioeconomic model for estimating the optimal level of deer and tag sales. For the biological component of his model, he used the Killvary population simulation model developed at the California Department of Fish and Game (Updike 1990). For the value estimates of a deer, estimates from a contingent valuation survey on California deer by Loomis et al. (1989) were used. Both consumptive and nonconsumptive values were considered. Estimates of the consumptive and nonconsumptive value of an average buck were approximately US$209 and US$20, respectively.

CHARACTERISTICS OF DVCS IN OHIO

Methods

Assuming that the current number of DVCs in a given area is greater than optimal, economic efficiency suggests that DVCs should be reduced to the point where the additional benefits gained from reducing DVCs are equal to the additional costs incurred at the margin. The benefits of reducing DVCs, as identified above, include reductions in property damage, human morbidity and mortality, and the loss of deer from DVCs. The costs, alternatively, will likely depend on the method or methods employed to reduce DVCs. Two general methods include installing various mitigation strategies such as fencing, signs, or reflectors, and reducing the deer population. Regardless of method, attaining the optimal number of DVCs will require that relationships be established between DVCs, the factors giving rise to them, and the resulting impacts on benefits and costs.

To help formalize our discussion of these potential relationships, we hypothesize, based on much of the research described above, that DVCs are influenced by the following factors:

$$DVC_C = f(\text{deer population density}_C, \text{traffic density}_C, \text{mitigation strategies}_C, \text{proximity to urban area}_C, \text{habitat}_C, \text{time of year}, \text{time of day}, \text{day of week}, \text{road conditions}_C, \text{weather conditions}_C) \quad (1)$$

where c identifies the location of the DVC. While these factors are not all encompassing, for instance vehicle speed is not included, they do include many of the major factors influencing DVCs in a particular area. Consider DVC characteristics in Ohio. Both traffic volume and DVCs have been on a steady rise. As shown in Tonkovich (1995), between 1977 and 1994, traffic volume on Ohio's highways rose at an average annual rate of 3.2% while DVCs increased in rural and urban areas on average 7% annually. Tonkovich also showed that, while day of the week seemed to have no influence on incidences of DVCs, month of the year and time of day were strongly correlated with DVCs. The 3 months with the highest incidences of DVCs was November, accounting for approximately 26% of the yearly total, and October and December, each with approximately 15% of the yearly total. DVCs across the remaining months ranged between approximately 7.5% of the yearly total in January down to roughly 3% in August. The highest occurrences of DVCs happened after 1700 hr (approximately 58%) and between 0500 hr and 0700 hr (approximately 20%). Clearly, the rut was a large component of these temporal effects. Finally, Tonkovich (1995) found that the majority of DVCs occurred under no adverse weather or road conditions.

Based on these 2-way relationships, most of the factors mentioned above seem to have either a strong positive or strong negative relationship with DVCs. Despite this evidence, a more rigorous analysis that accounts for other potentially confounding factors is required to effectively capture the relationship between any pair of variables. Indeed, both Tonkovich (1995) and Romin and Bissonette (1996a) called for more rigorous and sound research (rather than opinion) when drawing conclusions about the relationships between DVCs and various mitigation strategies. At the risk of exposing ourselves to similar criticism, we attempt to provide such an analysis in the remaining part of this section.

Results

The first relationship we investigate is between DVCs and deer population. Because actual deer population numbers are not available, a proxy must be used. We use buck-gun harvest per square mile (BHSQM). Given a panel data set of 88 counties from 1977 to 1998, we regress DVCs on BHSQM. As the results in column A of Table 1 illustrate, the coefficient on BHSQM is posi-

Table 1. Estimated coefficients on factors influencing deer-vehicle collisions in Ohio[a]

Dependent Variable: Deer Vehicle Collisions

	A	B	C	D	E	Athens	Williams
INTERCEPT (CONSTANT)	59.32***	-90.62***	-92.55***	-111.35***	-91.73***	-68.21	12.02
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.385)	(0.841)
VEHSQM		0.80***	0.80***	0.78***	0.75***	0.79	0.827
		(0.00)	(0.00)	(0.00)	(0.00)	(0.614)	(0.373)
ODPSADJ		71.25***	70.68***	59.36***	63.52***	6.67	49.83***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.760)	(0.006)
BHSQM	145.15***	60.96***	70.21***	78.02***			
	(0.00)	(0.00)	(0.00)	(0.00)			
DHSQM			-5.72	-16.28***			
			(0.208)	(0.001)			
BAG				24.55***			
				(0.00)			
BHSQMLAG					21.72*		
					(0.055)		
DHSQMLAG					-21.89***		
					(0.00)		
BAGLAG					24.12***	35.83*	-24.91
					(0.00)	(0.082)	(0.152)
TOTAL					0.04***		
					(0.00)		
LIVEBUCKS						0.12***	0.22***
						(0.001)	(0.00)
sample size (n)	1936	1936	1936	1936	1936	21	21
coefficient of determination R^2	0.48	0.74	0.74	0.75	0.75	0.95	0.92

[a] Panel data set from 1977-1998 across 88 counties. Estimated coefficients are estimated using Ordinary Least Squares and represent the slope of the linear regression line. Hausman test suggests a fixed-effects model. P-values are in parentheses. VEHSQM ~ number of registered vehicles in county per square mile; ODPSADJ ~ 0 for years 1977 to 1989 and 1 for years 1990 to 1998; BHSQM ~ buck-gun harvest in county per square mile; DHSQM ~ doe-gun harvest in county per square mile; BAG ~ bag limit in county; BHSQMLAG ~ buck-gun harvest in county per square mile from previous year; DHSQMLAG ~ does-gun harvest in county per square mile from previous year; BAGLAG ~ bag limit in county from previous year; TOTAL ~ total reported harvest of does and bucks in county for current year; LIVEBUCKS ~ estimated buck population in county. *,**,*** - statistically significant at the 10%, 5%, and 1% level, respectively.

tive and statistically significant at the 1% level. The R^2 suggests that BHSQM alone seems to explain 48% of the variation in DVCs.

In addition to the size of the deer population at a particular location, we hypothesize that traffic volume is an influential variable in predicting DVCs. As a proxy for traffic volume in each county, the number of vehicle registrations per square mile (VEHSQM) is used. After 1989, though, there was a change in the accounting procedures used by the ODPS in calculating registered vehicles per county. To control for this change, we include a dummy variable (ODPSADJ) that is equal to 0 for the years 1977 to 1989 and is equal to 1 for the years 1990 to 1998. Essentially, the trend (slope) across these 2 time periods is the same, but there is a level-effect induced by the alternative accounting procedure. By including this dummy variable, we capture and control for this level effect. The results from the regression of DVCs on both BHSQM and VEHSQM are shown in column B of Table 1. Both BHSQM and VEHSQM are of the expected sign and statistically significant at the 1% level. Note that the coefficient on BHSQM is less than in the first regression, suggesting that some of the variation in DVCs attributed to BHSQM in column A was via correlation with VEHSQM and not necessarily direct causation.

Clearly, does are involved in DVCs as well. To account for the impact of does on DVCs we include a proxy for the doe population, doe-gun harvest per square mile (DHSQM). As shown in column C, including DHSQM along with BHSQM and VEHSQM only mildly affects the coefficients on BHSQM and VEHSQM as compared to the previous regression. The coefficient on does is small, negative, and not statistically significant at even the 10% level. The lack of significance on DHSQM coupled with a drop in the t-statistics on the other coefficients (which are still statistically significant) suggest the presence of multicollinearity between DHSQM and BHSQM. Furthermore, while we would expect that the marginal impact of a buck on incidences of DVCs might be greater than the marginal impact of a doe, the negative sign on DHSQM deserves further explanation and investigation.

ODNR's management scheme has been quite consistent with respect to allowable buck harvest, essentially permitting 1 per year per hunter. Yet, ODNR has been increasingly aggressive in changing allowable doe harvest for population control purposes. It is well established that effective schemes for controlling deer populations rests with controlling the female population size. Thus observed changes in doe harvest rates are likely capturing changes in ODNR's management scheme to control deer population size while observed changes in buck harvest rates, with virtually no management changes, are likely capturing actual changes deer population size.

To illustrate how changes in allowable harvest impact DVCs, column D introduces the variable BAG, which is the total allowable harvest per hunter and varies across counties and over time. Since 1977, BAG has varied from a minimum of 0 to a maximum of 3 total deer and at most a 1-buck harvest. Hence, changes in BAG essentially reflect changes in allowable doe harvest. As column D shows, accounting for the impact of management changes on DVCs leads to a statistically significant negative DHSQM coefficient. So while BHSQM is positively correlated with DVCs, and serves as a proxy for current population sizes, DHSQM is negatively correlated with DVCs and serves as a proxy for changes in future population sizes. The positive and statistically significant coefficient on BAG is expected given that it, along with DVCs and deer populations, has increased over time.

There are 2 issues that arise with using BHSQM and DHSQM as proxies for current and future deer populations to explain DVCs, both of which are related to the fact that most DVCs within a year occur before hunting season. First, changes in deer populations from changes in doe harvest are likely to be realized in the year following the harvest change. Considering that Ohio deer (gun) hunting season begins the Monday following the last Thursday in November, the impact on DVCs for any particular year from changes in harvest rates in that year are likely to be confined to only those DVCs that occur in December. This suggests that the previous year's DHSQM may be a better proxy for population changes than current year DHSQM. Second, given that a buck seems to have a greater impact on DVCs than a doe, the previous year's buck-gun harvest rate may be a good predictor of future DVCs. It should be emphasized, though, that such conclusions of the relative impact of does versus bucks on future DVCs are likely to depend on the sex ratio of the population. For instance, Feldhammer et al. (1986), while also emphasizing the importance of the sex ratio of the population on doe to buck DVC rates, report a 2:1 ratio of doe to buck DVCs.

Finally, while these 2 terms capture the impact of the previous year's harvest on current year populations and DVCs, it important to also account for current year population effects. Since the correlation between any 2 years BHSQM is high, we use the current year total harvest of does and bucks, TOTAL, as a current year population proxy. In doing so, we account for harvest effects, population effects, and management effects.

In column E, we combine the previous year's buck and doe harvest per square mile (BHSQMLAG and DHSQMLAG, respectively) with the current year's total harvest (TOTAL). To be consistent with the impact of changes in management scheme on future populations, we also use the previous year's bag limits – BAGLAG – rather than the current year's bag limits. As the results

Table 2. Annual Deer-Vehicle Collisions Along 3 Highway Segments in Ohio[a]

Annual Number of Deer-Vehicle Collisions										
		1990	1991	1992	1993	1994	1995	1996	1997	1998
Defiance	Night	3	5	2	8	0	1	1	2	2
SR 15	Total	4	6	2	8	0	1	3	2	2
Hancock	Night	2	5	3	11	10	1	7	5	2
US 68	Total	3	6	4	14	14	2	8	5	3
Hancock	Night	0	3	0	2	3	0	0	1	0
US 224	Total	2	4	0	2	3	0	1	2	2

[a] Each highway segment is approximately 1 mile long.
Swareflex reflector installed on SR 15: 5/95. Accident in 1995 occurred after reflector installed.
Swareflex reflector installed on US 68: 2/95. Both accidents in 1995 occurred after reflector installed.
Swareflex reflector installed on US 224: 11/93. In 1993, 1 accident occurred after and 1 before reflector installation.
1996 observation for US 68 dropped due to poor maintenance of reflector

suggest, this year's population proxy – TOTAL – is positive and statistically significant as is the previous year's buck-gun harvest rate, BHSQMLAG. The previous year's does harvest rate, DHSQMLAG, is negative and statistically significant. All the other variables are of the expected sign and are statistically significant at the 1% level.

The positive coefficient on BAGLAG can be interpreted as a signal that the ODNR recognizes populations are increasing. Given a particular bag limit, then, we would expect the increase in doe harvests will negatively impact DVCs. This sign may also be capturing the fact that a doe harvested may be a pregnant doe and thus, in effect, has a greater impact the future DVCs. The positive coefficient on the previous year's buck harvest is still capturing increases in population as is the positive coefficient on TOTAL.

Admittedly, there may be some noise involved in this analysis given the unit of aggregation is at the county-level, we employ numerous proxies, and we do not account for the use of mitigation strategies over time and across counties. In an effort to investigate the relationships suggested in equation (1) in a more disaggregate manner, we use data collected by the Ohio Department of Transportation (ODOT) on DVCs along 3 1-mile road segments in rural Ohio (C. Schreck, Ohio Department of Transportation, unpublished data). Table 2 provides a summary of these data. The data were collected from 1990 to 1998 on DVCs along a single-mile road segment of SR 15 in Defiance County, Ohio, and 2 separate single-mile road segments along US 68 and US 224, in Hancock County. Both of these counties are in northeastern Ohio.

The purpose of the ODOT in collecting these data was specifically to investigate the effectiveness of Swareflex reflectors. Along SR 15 in Defiance County, the Swareflex reflector was installed in May of 1995. The single accident reported along SR 15 in 1995 occurred after the installation of the reflector. Along US 68 in Hancock County, the Swareflex reflector was installed in February of 1995. Both reported DVCs along US 68 in 1995 occurred after the installation of the reflectors. The Swareflex reflectors were installed along US 224 in November of 1993. Of the 2 accidents that occurred along US 224 in 1993, 1 accident occurred before installation of the reflector while the other accident occurred after the installation. Finally, while there seems to be continuing efforts by the ODOT to collect similar data for future analyses, at the time of this analysis, we were limited to analyzing the data presented in Table 2. Table 2 lists both the total number of DVCs per year along each segment and also a subset consisting of those DVCs that occurred at night alone.

Given the small sample size associated with each site, the 9 observations from each site are pooled for a total of 27 observations. Grass was discovered covering 1 of the reflectors along US 68 in Hancock in 1996, and thus we dropped this observation from the data set leaving us with 26 observations. Because the dependent variable is a non-negative integer whose mean is close to 0, a more appropriate modeling strategy is to use some count-based estimator. We employ a Poisson model. A likelihood ratio test suggested that we reject the null hypothesis of a pooled Poisson estimator in favor of a panel Poisson estimator. A Hausman test suggested that the appropriate econometric approach was a random-effects model. Since neither traffic volume data nor deer density data were available for any of the individual sites, county-level data (TOTAL, VEHSQM, and BHSQMLAG) were used as proxies to capture potential county-level trends associated with these factors. While we used both BHSQMLAG and DHSQMLAG with the county-level aggregate data in Table 1, we use only BHSQMLAG here. Given the low degrees of freedom and the result that BHSQMLAG seems to have a greater impact on DVCs than DHSQMLAG, choosing BHSQMLAG seemed appropriate. Finally, to account for the effect of the reflectors on DVCs, we use a dummy variable (REFLECTO) that is equal to 0 for the years (and DVC incidences) before the installation of the reflectors and equal to 1 for the years (and DVC incidences) after the reflector installation.

To get an understanding of how the relationships derived from combining more micro-level data from

Table 3. Estimated coefficients on factors influencing deer-vehicle collisions along three highway segments in Ohio[a]

Dependent Variable: Deer-Vehicle Collisions

	A Total DVCs	B Night DVCs	C Total DVCs	D Night DVCs	E Night DVCs
INTERCEPT (CONSTANT)	2.25	2.30	-0.36	-0.42	-0.13
	(0.151)	(0.214)	(0.849)	(0.848)	(0.947)
VEHSQM	-0.006	-0.009	0.014	0.006	0.012
	(0.536)	(0.454)	(0.271)	(0.699)	(0.334)
REFLECTO			-0.78**	-0.59	-0.58
			(0.02)	(0.137)	(0.114)
TOTAL	0.003***	0.003***	0.002***	0.003***	0.002***
	(0.000)	(0.000)	(0.009)	(0.002)	(0.002)
BHSQMLAG	-3.66***	-4.39***	-2.05	-3.21**	-2.54*
BAGLAG					-0.15
					(0.18)
sample size (n)	26	26	26	26	26
	18.28	20.96	21.82	21.52	24.09
	(0.0004)	(0.0001)	(0.0002)	(0.0002)	(0.0002)

[a] Panel data set from 1990-1998 over 3 segments. Locations include a 1-mile highway segment in Defiance County and 2 distinct 1-mile segments in Hancock County. Given the non-negative integer values for the dependent value, the coefficients are estimated using a Poisson model. P-values are in parentheses. Hausman test suggests a random effects model. Wald test statistic for nonlinear models tests joint hypothesis that all coefficients are zero. A likelihood ratio test rejects the null hypothesis of a pooled estimator. VEHSQM ~ number of registered vehicles in county per square mile; REFLECTO ~ zero/one dummy variable for presence of reflector; TOTAL ~ total reported harvest of does and bucks in current year; BHSQMLAG ~ buck-gun harvest in county per square mile from previous year; BAGLAG ~ bag limit in county from previous year; *,**,*** - statistically significant at 10%, 5%, and 1% level, respectively.

these 3 highway segments with aggregate proxies compare to the aggregate results from Table 1, columns A and B of Table 3 show the results from regressing DVCs – both total and nighttime total – on registered vehicles per square mile (VEHSQM), a 1-year lag of the buck-gun harvest per square mile (BHSQMLAG), and total harvest of does and bucks (TOTAL). While all the coefficients are of the expected signs and similar to the analysis provided in Table 1, VEHSQM is not statistically significant in either column A or B. This result is not surprising given the potential noise associated with using vehicle registration at the county-level to capture traffic densities along these 3-mile segments.

In columns C and D the impact of Swareflex reflectors on the incidences of DVCs is analyzed. Obviously, these reflectors do not work during the day. Yet, it is interesting to note that whether our dependent variable measures total DVCs or only those DVCs occurring at night, the coefficient on REFLECTO is negative and, surprisingly, statistically significant when the dependent variable is total DVCs.

While the sign on these results may suggest promise for the use of reflectors on DVC reduction, there may be some correlation between the installation of the reflectors and, perhaps, some type of aggressive population management scheme. To account for potential deer management effects, in column E we include the previous year's bag limit. As illustrated, the sign on REFLECTO is still negative, yet as with column D, it is not significant at the 10% level.

Obviously the small sample size and fewer degrees of freedom are of concern. These results suggest that the robustness of the impact of reflectors on DVCs, while consistently negative, varies in statistically significance. Furthermore, while these results may be construed to suggest a potential negative impact on DVCs from installing reflectors, before any conclusions are drawn the results should be compared with theory. That is, from a biological perspective, why might deer behave differently in the presence of the reflectors? While this issue does not seem to be resolved completely, work by Ujvari et al. (1998) suggested that deer do not behave differently, at least after habituation, to the presence of the reflectors. Perhaps drivers are responding differently in the presence of the reflectors (Zacks 1986).

While we acknowledge that there are difficulties with both sets of models presented above, particularly the level of aggregation of the data in Table 1 and the small sample size and lack of road specific information on traffic volume and deer populations in Table 3, these results coincide with some findings in the literature. First, both traffic volume and deer populations would seem to impact DVCs positively (Tonkovich 1995, Romin and Bissonette 1996b). Second, reducing the deer population, particularly the buck population, may be an effective means of reducing DVCs. Indeed, research by Romin and Bissonette (1996b) suggested that bucks accounted for proportionately more DVCs than their representation in the population. Third, Swareflex reflectors are negatively correlated with DVCs along 3 road segments in rural Ohio. Finally, given that the pooled estimators are consistently rejected in favor of panel estimators, locational factors or habitat characteristics that differ across counties seem to play a significant role in explaining DVCs.

While these results may or may not be surprising, they do emphasize both a reasonable approach for investigating these issues and the importance of more detailed analyses investigating even further the factors giving rise to DVCs. For example, the work by Bashore et al. (1985) and Romin and Bissonette (1996b) accounted for specific characteristics of habitat and roadway construction in the investigations of DVCs. Such detailed analyses provided the types of information necessary for policy makers to make informed decisions. And while our analysis is somewhat more general, the results suggest that such detail is needed to fully understand the factors influencing DVCs.

Noticeably absent from this discussion of the characteristics of DVCs in Ohio has been any mention of the costs. Obviously, the costs per accident are going to depend on a number of factors, including size of deer, type of vehicle, speed of vehicle, and insurance rates. While DVC economic-related data is limited, the ODPS does keep statistics on the number of DVCs. ODPS has DVC crash-related statistics on both the seriousness of the crash and a dollar value attached to each crash based on the National Highway Traffic Safety Administration's (NHTSA) 1991 estimates of the average cost per accident, categorized according to the reported seriousness of the accident (personal communication, D. Bowens, Statistical Supervisor, ODOT, 1998). Using ODPS data from 1990-1998, there were a total of 143,016 reported DVCs. Recall that for a deer-related vehicle accident to be reported as a DVC requires a minimum of US$150 of damages. Of the 143,016 reported accidents, 14 resulted in human fatalities resulting in an approximate 0.01% probability of death. Of those accidents having some type of morbidity effects, 247 (0.17%) resulted in serious injuries, 3,844 (2.7%) resulted in mild injuries, and 6,892 (4.82%) resulted in claimed injuries. Finally, as mentioned above, there were 132,019 (92.3%) accidents that were reported but did not result in any claimed injuries.

The ODPS reports the average cost per vehicle accident to estimate annual losses from DVCs. These average costs are categorized by the reported seriousness of the accident (death, serious injury, mild injury, claimed injury). The expected cost of a DVC is calculated by summing across each "seriousness" category the average cost associated with the seriousness of the event multiplied by the probability of that particular event. Following this approach, the expected cost associated with the death component of a DVC is US$235, US$289 for a serious injury, US$891 for a mild injury, and US$819 for a claimed injury. These estimates are based on the following loss or cost per event (ODPS 1998): US$2,393,000 (death), US$170,000 (serious injury), US$33,000 (minor injury), and US$17,000 (claimed injury). Finally, since at least US$150 of damages must be incurred for it to be reported (therefore imposing a lower bound on reported collisions), US$138 is the expected cost for a collision without any type of injury. Clearly, this is an underestimate of the costs strictly associated with automobile damage and should be updated when more accurate information becomes available. Summing up these expected costs gives us an average DVC cost estimate of approximately US$2,372. While these cost estimates do not come from actual DVC accidents, it is not evident that a reported serious or mild injury from a DVC should differ greatly from a reported serious or mild injury from some other type of vehicle accident.

The next section will combine this information on costs with a few simple estimated relationships between DVCs and harvest rates to evaluate the impacts of DVCs on optimal deer management, especially with respect to the desired optimal steady state population size.

SIMULATING CHANGES IN DVCS WITH A DYNAMIC POPULATION MODEL

Methods

From a practical perspective, there are 2 general means for reducing the incidence of DVCs in a given area: through the active use of DVC mitigation practices or by reducing the population of deer through changes in hunting regulations. Both DVCs and harvest depend on the dynamics of deer population growth and this growth in turn depends on DVCs and harvest (e.g., McCullough 1979, Downing and Guynn 1983, Guynn 1985). To facilitate an analysis of changes in the incidence of DVCs on harvest rates and deer population growth, we represent the dynamic interactions between harvest, DVCs, and the population of white-tailed deer in Ohio with a simple system of ordinary differential equations (ODEs) that can be numerically solved. The 3 principle populations of concern are bucks (adult males), does (adult females), and fawns (juvenile deer). We can simulate the effects of changes in DVCs and hunting regulations on the size and growth of these populations by allowing the behavior of the ODE system to be controlled through parameter restrictions. Consequences of these changes can then be evaluated by comparing the characteristics of the system's solution before and after the regulatory change.

Growth of an exploited population over time will be a function of the natural growth rate and the rate at which the population is harvested and otherwise killed. For this analysis, we overlook the impact of immigration and emigration on the natural growth rate of the population, or alternatively, we assume these 2 effects net to 0 in a steady-state scenario. Given that the natural growth of the deer population is also subject to constraints imposed by the characteristics of the environment, we assume that the natural growth of the population follows a logistic pattern subject to annual harvest and DVC mortality. Logistic growth is a modification of standard exponential growth, and is commonly employed in modeling natural populations. The characteristic 'S' shape of the logistic function reflects the fact that due to crowding and limitations on natural resources, exponential growth cannot continue indefinitely. At the beginning of the logistic curve, where population size is relatively small and carrying capacity constraint not binding, growth approximates exponential growth. As population increases and the carrying capacity is approached, growth begins to saturate (Luenberger 1979). Logistic natural growth in a particular area c, then, can be described by the first term in each of the following differential equations:

$$dB_c/dt = b_B B_c(1 - B_c/k_{Bc}) - h_B B_c - v_B B_c \quad (2)$$

$$dD_c/dt = b_D D_c(1 - D_c/k_{Dc}) - h_D D_c - v_D D_c \quad (3)$$

where B and D represent the sizes of the buck and doe populations respectively, b_B and b_D are the intrinsic natural growth rate of the buck and doe populations, respectively, and k is the carrying capacity of the environment. From this logistic growth we subtract hunting mortality (at rate h times the population size) and vehicle mortality (at rate v). We also model the unharvested fawn population as a simple function of the equilibrium doe population, based on the number of fawns each doe produces annually:

$$F_c = 1.7D_c \quad (4)$$

Fawns are harvested at some rate, h_f, and killed by collisions with vehicles at rate v_B. Given a set of values for the 4 parameters of each differential equation and for the fawn harvest and DVC rates, we can solve for the population sizes necessary for the system to be in a steady state by setting each of the ordinary differential equations equal to 0. As the deer population in Ohio has been approaching a stable level due to aggressive management policies, rather than solving for equilibrium population size we instead impose the assumption that the populations are in equilibrium. Given this assumption, we can solve for the growth rate that allows the current stable population to equal our estimate of the present deer population. In essence, we use the intrinsic natural growth rate as the calibration parameter.

Results

To use our model to simulate the effects of changes in the incidences of DVCs on deer population size and harvest, we must first calibrate out model such that the equilibrium population size matches the estimated size of the current population of bucks in Athens County. In Athens County we have an estimate of the 1996 (assumed to be stable) population size of approximately 2,300 bucks using a buck-harvest rate of 63% -- i.e., h_B is equal to 0.63. Employing suggested ratios of bucks to does and does to fawns, the number of deer that can be supported per square mile, and the size of Athens County, we derive a carrying capacity for bucks of 4,658. This estimate is based on conversations with ODNR Division of Wildlife officials (1999). Specifically, we assume a 1.6:1 ratio of does to bucks and a springtime 1.7:1 fawn to doe ratio. Finally, we assume 1996 populations are being managed at 55% of maximum carrying capacity.

To estimate the relationship between bucks and DVCs, v_B, we transform our buck-harvest per square mile data in Athens County to a buck population estimate (LIVEBUCKS) and regress DVCs on this factor and VEHSQM. The buck population, LIVEBUCKS, is calculated by dividing BHSQM for Athens County by 0.63 and multiplying that estimate by the area of the county. As Table 1 illustrates under the *Athens* column, a 1-unit increase in the number of bucks in Athens County, controlling for vehicles per square, leads in an increase in DVCs of 0.12. Given the small sample size and concerns about our degrees of freedom, we limit our explanatory variables to these 2 factors – both of which have been shown to be quite robust to other specifications.

Given a calibrated model, we can now simulate the effects of changes in the incidence of DVCs on deer population size and harvest. For example, assuming that the initial DVC rate is 0.12 for bucks and 0.04 for fawns and does, we can simulate the effects of decreasing this rate through mitigation practices by altering its value and solving for new equilibrium conditions. Alternatively, we can assume that the DVC rate remains constant, but that the number of DVCs is reduced through changes in harvest pressure (currently 0.63 for bucks and 0.20 for fawns and does). Finally, we can examine a combination of these means to reduce DVCs.

We assume that the installation of a particular DVC mitigation strategy will reduce DVCs by 85%. While we chose 85% for illustrative purposes and emphasize that other estimates would have illustrated our intentions, conversations with wildlife mitigation strategy experts (Romin 1996, personal conversation, Neve, D.G., Hi-tech fences 1996, personal conversation) suggest Z-clip fencing can achieve an 85% effectiveness reduction. At current harvest rates, then, an 85% decrease in the DVC rate in Athens County causes the equilibrium population of deer to increase such that

185 additional bucks, 153 additional does, and 230 additional fawns could be harvested per year. Coupled with the change in population size, this 85 % decrease in DVCs translates into approximately 550 fewer accidents with deer each year in Athens County. Conservatively estimating the value of a harvested deer at US$180 (Schwabe et al. 2001) and using the cost per DVC estimate of US$2,372 described above, an 85% decrease in the DVC rate results in approximately US$102,240 in additional benefits to hunters and US$1,304,809 in DVC cost savings. Based on these results, we can conclude that strategies to reduce DVCs in Athens County that can be implemented at a cost of US$1,407,049 or less per 85% reduction in DVCs are economically efficient.

It is important to note that changes in deer populations are likely to lead to changes in the size of the deer harvested in a similar manner as suggested by Guynn (1982). Such changes in the size of the deer may have impacts on the value of a deer. Also, while we do not differentiate here between the value of a buck, doe, or fawn, acknowledging such differences may also have potentially large impacts on the value of the harvest and thus the over-all benefits estimate.

It is also important to acknowledge that because deer populations differ markedly across the state, the effects of a given percentage reduction in DVCs will vary across counties. For example, we can contrast the above results for Athens County (located in the eastern part of Ohio) with those for Williams County (located in the western part of Ohio). As highlighted in Table 1 under the Williams column, Williams County has a DVC to buck ratio of 0.22. Given this coefficient, a different carrying capacity, and the same assumptions regarding doe and fawn harvest and DVC rates as in Athens County, an 85% reduction in the DVC rate will result in the opportunity to harvest 65 additional bucks, 48 additional does, and 72 additional fawns. Furthermore, there will be approximately 196 fewer accidents. Such results, using the same dollar values as above, lead to approximately US$33,300 in benefits to hunters and US$464,986 in cost savings from accidents.

An alternative to installing DVC mitigation strategies is to alter the hunting regulations so that greater hunting pressure will decrease the size of the deer population and in theory, lead to fewer DVCs. This could be accomplished by either increasing the length of deer hunting season or issuing more deer hunting permits. For illustrative purposes, we assume that a 7.6% increase in the deer harvest rate could be achieved by increasing the length of Ohio deer hunting season by 1 day – in effect changing current deer (gun) season in Ohio from 13 to 14 days. In Athens County, such a change would decrease the equilibrium populations of bucks, does, and fawns such that approximately 50 fewer deer would be harvested (14 does, 21 fawns, and 15 bucks) and 55 fewer DVCs would occur. Because of density dependent responses in productivity and recruitment, a decline in harvest would be unlikely in most situations today. However, productivity data from Ohio strongly suggests that herds in the eastern and western portions of the state reside at maximum sustained yield (MSY) and very likely to the left of MSY, respectively. In economic terms, 50 fewer deer and 55 fewer DVCs lead to US$9,000 in lost benefits to hunters but US$130,460 in reduced costs from DVCs.

In Williams County, our estimates suggest that total deer harvested would stay approximately the same, although there would be 18 fewer DVCs, leading to a cost savings of US$42,696. The reasoning behind this latter outcome is that while harvest totals remain the same, the composition of harvest changes. In Williams County, increasing harvest rates for each population results in harvesting 5 additional bucks, 2 fewer does, and 3 fewer fawn as compared to the pre-harvest increase. The desirability of such a policy change will likely depend on the relative sizes of the losses in benefits to hunters and the potential gains in terms of net cost savings from DVCs.

Finally, we simulate the effects of a combination policy where both hunting regulations and active DVC mitigation practices are employed. We use the same values from the individual simulations above, an 85% reduction in the likelihood of a DVC and a 7.6% increase in harvest rate. In Athens County, this combination of policies causes a net increase in the size of all deer populations, such that total deer harvested can increase by approximately 580, and 560 fewer DVCs will occur. This combination of benefit increases and cost reduction leads to a gain of US$1.4 million. In Williams County, total harvest will increase by approximately 200 deer – 75 bucks, 50 doe, and 75 fawn – and DVCs will decrease by an equal amount for a total gain of over US$500,000. Clearly this combination policy results in higher net benefits than either policy alone. But again, cost estimates need to be considered to satisfy efficiency conditions.

While the results of these simulations depend critically on the assumed growth functions, the accuracy of our calibrations, and the assumed harvest and mortality rates for buck, does, and fawns, we can form some general conclusions. First, mitigation strategies that are effective have the opportunity to provide substantial benefits to both drivers and hunters alike. Before a conclusion can be drawn about the efficiency of such strategies, though, the benefits of implementing any mitigation strategy must be compared to the costs of implementation. Second, changing hunting regulations are another means of reducing DVCs with added potential benefit to hunters from greater harvests. An implicit assumption of course is that herds are currently being managed as most are, somewhere between

65% and 80% of carrying capacity. While aggressive antlerless harvests will reduce overwinter herd size and presumably DVCs, harvests should increase due to density dependent responses in productivity and recruitment. Herds managed according to social tolerances rather than biological limits, such as those in western Ohio and other heavily farmed sections of the Midwest, would likely experience not only a reduction in DVCs with a population reduction, but also a decline in harvest as well.

While the benefits of changing population size might seem modest when compared to implementing some type of DVC mitigation strategy, the costs of implementation are likely to be more modest as well. Furthermore, changing population size does not include dealing with the uncertainty surrounding the potential effectiveness of many DVC mitigation strategies. Finally, the combination of implementing a DVC mitigation strategy and changing population size via hunting regulations is shown to offer the largest potential benefits. Yet again, judgments as to the efficiency of this strategy relative to the other strategies must be deferred until implementation and maintenance costs are introduced. Regardless of strategy though, as long as the potential gains from reducing DVCs via changes in hunting regulations or mitigation strategies are greater than the costs of implementing these strategies, a potential economically efficient improvement is available.

CONCLUSION

More than 500,000 DVCs occur annually in the US and resulting in losses in excess of US$1.2 billion from property damage, human injury, and human mortality. In Ohio, with roughly 26,000 DVCs per year, the estimated annual losses are greater than 3 times the revenue generated from the sale of hunting licenses and deer permits combined. This research has investigated factors that seem to influence the incidences of DVCs in Ohio. Similar to the conclusions found in research by Allen and McCullough (1974), Culbertson and Stoll (1990), and Romin and Bissonette (1996a), our results suggest that factors such as population sizes, traffic volume, habitat, and time all influence the incidences of DVCs in Ohio. Using aggregate county-level data, trends in vehicle registration and buck-gun harvest per square mile are strongly correlated with DVCs and, based on the specifications evaluated in Table 1, are quite robust. Furthermore, after accounting for changes in bag limits across counties and over time, doe-gun harvests per square mile also prove to be strongly correlated with DVCs. Given that the ODNR manages populations by changes in allowable doe harvest while leaving buck harvest management schemes relatively unaltered, our results are not surprising. Yet, given that optimal deer management may require adjustments to population size when confronted with such exorbitant human-deer conflict, additional information that the marginal impact of a buck on DVCs is greater than the marginal impact of a doe may prove useful.

Such results are not simply fodder for academic grist. For instance, our results suggest that while reducing populations will likely lead to fewer DVCs, targeting the buck population will have a larger effect than targeting doe populations. Furthermore, given the very predictable geographic pattern of white-tailed deer in Ohio, the strong correlation between proxies for traffic volume and incidences of DVCs, and the large potential benefits from reducing the rate at which DVCs occur, public awareness campaigns educating drivers of these characteristics would seem to be both a potentially effective and rewarding mitigation strategy. Indeed, given the apparent lack of research investigating the impact of this latter mitigation strategy, our results suggest that the potential gains from more research could be large.

Finally, we considered 2 general strategies for reducing DVCs – reducing the rate at which DVCs occur via mitigation strategies and using hunting regulations to reduce the deer population. While both methods show potential gains, a combination of the 2 seemed to be the most effective and may provide the largest net gains. Clearly, the results will depend on the costs of implementing these strategies. Furthermore, given uncertainty about the effectiveness of DVC mitigation strategies, the relationship between reductions in deer populations and DVCs, and the relationship between deer saved from DVCs and deer harvest, our results should be read with caution. That is, it is clear that the assumptions used in this analysis are at least in part driving the results. However, it is important to note that while relatively simple, the models used in this work do show a great deal of promise in providing explicit empirical linkages between hunting policy, deer vehicle collisions and economic values.

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