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An Interactive Model of Human and Companion Animal Dynamics: The Ecology and Economics of Dog Overpopulation and the Human Costs of Addressing the Problem

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Companion animal overpopulation is a problem of human creation with significant human costs that can only be addressed through human action. A model was constructed to understand the dynamics of canine overpopulation and the effectiveness of various policy options for reducing euthanasia. The model includes economic and ecological factors in human and dog populations. According to the model, a "no-kill" society is an achievable goal at an acceptable human cost. Spay/neuter programs were generally found to be the most effective, with increasing adoptions also being an effective option. However, spay/neuter policies need to be evaluated over a very long time horizon since full impact may not be achieved for 30 years or more. Spay/neuter efforts can have a large impact even if they only effect a small portion of the human population. Adoption and spay/neuter programs were found to work well in combination, and to continue being effective as society approaches "no-kill" dynamics.

KEY WORDS: **A1**

INTRODUCTION

Human companion animal overpopulation is a problem of human creation with significant human costs that can only be addressed through human action. In many respects, companion animals lie in an unusual gray area

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between the human world and the natural environment. Legally and economically, these animals are property and a tradable "good" and therefore lie within the realm of industrialized human society. However, at the same time, companion animals are also a connection between human society and the natural environment.

In addition, humans have a certain responsibility for the welfare of companion animals. Dogs, the focus of this study, have been bred for thousands of years to serve our needs. They have therefore ceased being truly "wild" animals and instead become dependent on humans for survival. As the creators of a species dependent on humans, we have a certain responsibility for that species' welfare. Humans also have a responsibility for addressing dog overpopulation since they are in a sense the perpetuators of the problem. Pet store suppliers, commercial breeders, and private owners (or "backyard breeders") intentionally produce millions of animals every year to meet public demand. Millions of consumers initially decide to purchase or adopt a dog, only to later abandon that animal because it is inconvenient or no longer suits their needs. Millions more choose not to spay or neuter their dog. Therefore, it is human actions and inaction that perpetuate dog overpopulation and create the need for the human-made "solution" of euthanasia.

Although the estimates vary, there is no doubt that millions of dogs and cats are put to death every year in the United States. Arkow (1994) extrapolates data from nine states to come up with a national estimate of 8.3 million animals sheltered and 5.7 million euthanized. Rowan (1992) reports that the number of animals being euthanized is 5–6 million. Mackie (1992) estimates 7–15 million animals euthanized, Thornton (1991) estimates 16 million, and Carter (1990) estimates 13–17 million.

Focusing specifically on dog overpopulation, there are multiple costs to human society. According to Rowan (1992) shelters spend approximately $1 billion every year to deal with unwanted companion animals. Baetz (1992) estimates that $500 million is paid each year for animal control by United States cities and counties. Other costs include dog bites which result in 20 deaths and 585,000 injuries a year (Pediatrics, 1994). According to Beck *et al.* (1975) the reported bite rate in urban areas from all dogs (strays and owned) is 0.45%. However, according to Jones and Beck (1984), a high percentage of animal bites go unreported to authorities. There are other unexpected costs. Carding (1969) found that 6% of all automobile accidents and 1.2% of accidents involving death or injury to humans involved dogs.

Beyond these physical costs there are the psychological costs suffered by humans sympathetic to the plight of animals. According to Jasper and Nelkin (1992), 20% of Americans have contributed money to an animal protection organization, and 10–15 million Americans belong to at least one animal welfare group. Congress also receives more letters about animal welfare than any other topic (Fox, 1990).

But if animals are assumed to have interests independent of any human sympathy, the greatest cost is the impact on the animals themselves. This is a somewhat controversial assumption, but a growing number of philosophers and scientists are positing its validity including Singer (1975) and Regan (1983). A3

Although millions of dollars are currently being spent to reduce the number of animals euthanized, there has been little rigorous scientific analysis to direct these efforts down the most fruitful paths. This study builds a mathematical population flow model that includes both economic and ecological factors in human and dog populations to understand population dynamics and to analyze the effectiveness of various policy options that can be used to reduce dog overpopulation resulting in euthanasia.

One very promising method of addressing overpopulation is increasing spay/neuter rates. However, low-cost spay/neuter programs have been the subject of some controversy. While some experts believe increasing spay/neuter rates is the key to long-term population control, others, particularly in the veterinary community, argue that low-cost spay/neuter programs are ineffective.

Rush (1985) attributes improvement in Los Angeles animal shelter statistics in the period examined to low-cost sterilization and differential licensing (i.e., charging more for licenses for nonsterilized animals). However, Rowan and Williams (1987) present a possible alternative interpretation relating to changing demographics in the city leading to a decline in dog ownership. Their logic may explain some of the drop observed in licensing, but it does not explain the change in sterilization figures. The authors argue that the clinic was not responsible for most of the change in sterilization figures since they estimate that only 8000 out of approximately 75,000 sterilizations were performed by the clinic, the rest by veterinarians. However, their estimates of the total number sterilized are based on a probably inaccurate assumption that dogs switching owners or going into shelters are licensed in the same proportion as dogs in general. The authors also cite a study by Grayhavens (1984) as support for the view that a licensing drive did not increase the number of animals spayed and neutered. However, their logic is faulty here, confusing the number of dogs spayed/neutered with the percentage. The authors state that since the number of dogs licensed went up 48% but the percent altered only went up 4%, spay/neuter behavior was not effective. In fact, the study says just the opposite if one assumes that the marginal owner (the ones affected by the drive) had a lower spay/neuter percentage than owners who normally license their dogs.

Other evidence on the sterilization issue includes a study of Colorado Springs by Arkow (1985). The presence of a sterilization program in that community was correlated with a significant decline in the number and percentage of the total pet population handled by the shelter. Hodge (1976) cites the decrease in pet reproduction during the early 1970s as evidence that low-cost spay/neuter programs work, although he also gives credit to enforcement and education programs. He also points out that sterilization can reduce behavioral problems which are a major cause of pet abandonment.

Schneider (1975) argues that low-cost neutering services are not a good solution and instead advocates that controlling demand is the key to reducing the excess dog population. However, his conclusion is partially based on the high-turnover rate found for animals in the study area. In addition, older animals were found to have higher spay rates (but of course this is logically inevitable since once an animal is spayed it stays spayed, unless spayed animals die at a higher rate). From these facts Schneider concludes that owners are reluctant to spay animals because they may not stay long in the household. The flaw in this logic (other than its weak factual basis) is that owners who are reluctant to spay/neuter animals for this reason may be particularly sensitive to the price of the procedure since they allegedly are making a probability-based cost–benefit calculation.

According to MacKay (1993), "the belief that cost is an important barrier to sterilization has never really been borne out in any major survey" (p. 920). Yet a page earlier, the author states that comparison shopping has made the surgery unprofitable for veterinarians, which would seem to imply that consumers are very price-sensitive for this service. Even if we accept the author's claim that no major survey has shown that cost affects sterilization rate, he does not cite any evidence showing the opposite is true, and in the absence of evidence it would appear to be reasonable to assume that cost plays some role. The author also estimates that 95% of sterilizations are done by private practice veterinarians.

Beck (1983) also concludes that there is little evidence that people use
A4 spaying programs, citing statistical evidence from Beck (1973) and Modern Veterinary Practice (1973a,b), so that spay and neuter programs are "much ado about nothing." Clearly, expert opinion has been divided regarding the importance of sterilization. More rigorous analysis needs to be done. One of the intentions of this study is to shed some light on this topic.

METHODS

A generalized population flow model was constructed to be flexible enough to apply to any region and to incorporate the impact of policy options.

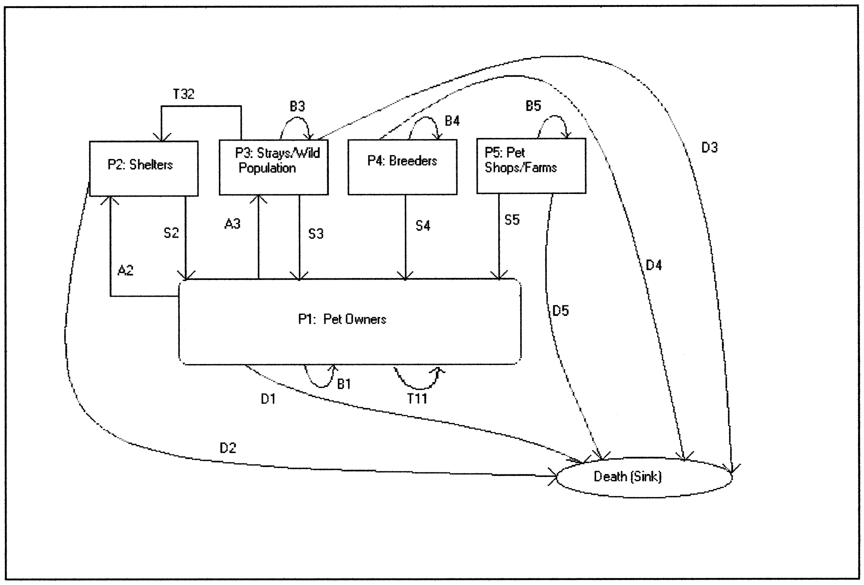

Fig. 1. Diagram of dog population flow dynamics model.

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The model was then calibrated on the basis of information obtained for one particular region.

Figure 1 shows the shows the ecological–economic model that is used here. The diagram shows all stocks (labeled "P" followed by a numeral for a population of animals) and all flows ("S" represents supply lines to the consumer pet market, "B" represents animal births, "D" represents deaths, "A" represents abandoned animals, and "T" represents other transfers).

The change in each population is defined by simply adding the flows in and out of the population with the starting values calibrated on the basis of the results of a survey of the Capital Region of New York State. Each flow equation is defined mathematically and also calibrated on the basis of survey data and prior research results. Table I gives the equations and values used for all model parameters. Populations are defined in the Table by their change, with starting values based upon the survey results for the Capital Region. Births in the human-owned population and stray populations are defined ecologically (by a birth rate, the spay/neuter rate, and the population size), while in the pet store and breeder population they are assumed to be managed to match the level of demand. The model implicitly assumes that there is some "supply push" from the stray population in that the number of strays adopted is a function of how many strays there are in the population. In addition, while the demand for dogs from other sources goes down

Table I. Model Equations and Parameters

Variable Name	Description	Formula or value
	Populations	
P1	Companion animal owners/guardians	ΔP1 = B1 + S3 + S4 + S5 − D1 − A2 − A3
P2	Shelters and rescuers	ΔP2 = A2 + T32 − S2 − D2
P3	Strays/feral population	ΔP3 = A3 + B3 − T32 − S3 − D3
P4	Breeders	ΔP4 = B4 − S4 − D4
P5	Pet Stores	ΔP5 = B5 − S5 − D5
	Endogenous variables	
B1	Births in P1	P1 × (1 − SN1) × BR1
B3	Births in P3	P3 × (1 − SN3) × BR3
B4	Births in P4	S4 + D4
B5	Births in P5	S5 + D5
D1	Deaths in P1	1/LS1 × P1
D2	Deaths in P2	A2 + T32 − S2 − (Ssp − P2)
D3	Deaths in P3	1/LS3 × P3
S2	Supply of dogs from shelters	TD × S2F − (S2F/(S2F + S4F + S5F)) × S3 × SF
S3	Dogs adopted from stray population	α3 × P3 − β3 × P1
S4	Supply of dogs from shelters	TD × S4F − (S4F/(S2F + S4F + S5F)) × S3 × SF
S5	Supply of dogs from shelters	TD × S5F − (S5F/(S2F + S4F + S5F)) × S3 × SF
A2	Dogs abandoned to shelters	α2 × P1 − β2 × B1
A3	Dogs abandoned/lost to stray pop	χ3 × P1 δ3 × B1
T32	Strays put in shelters	P3 × AC/(1 + AC)
	Exogenous variables	
D4	Deaths in P4	0 (shown only for completeness)[a]
D5	Deaths in P5	0 (shown only for completeness)[a]
T11	Transfers between consumers	0 (shown only for completeness)[a]
SN1	Spay/neuter rate (owned population)	0.89 (from regional survey)[b]
SN3	Spay/neuter rate (stray population)	0.68 (author's estimate)[c]
BR1	Birth rate—owned population	1.03 (from regional survey)[b]
BR3	Birth rate—stray population	0.098 (from regional survey)[b]
LS1	Life span (owned population)	0.098 (from regional survey)[b]
SSp	Shelter space	141 (from local shelter statistics)[d]
LS3	Life span (stray population)	1 year[e]
TD	Total initial demand (all sources)	10,575 (from regional survey)[b]
S2F	Adoptions as a percent of all demand	29.3% (from regional survey)[b]
S4F	Breeder demand as % of all demand	25.3% (from regional survey)[b]
S5F	Store demand as % of all demand	9.7% (from regional survey)[b]
SF	Stray intake factor	0.5 (author's estimate)[f]
AC	Animal control factor	0.2 (from local shelter statistics)[d]
α2	Impact of pop size on shelter abandonment	0.029 (from local shelter statistics)[d]
β2	Impact of birth rate on shelter abandonment	0.069 (from local shelter statistics)[d]

Table I. (*Continued*)

Variable Name	Description	Formula or value
$\alpha 3$	Impact of # of strays on stray adoption	0.11 (author's estimate)[f]
$\beta 3$	Impact of # of owned dogs on stray adoption	0.002 (author's estimate)[f]
$\chi 3$	Impact of # of owned dogs on new strays	0.29 (author's estimate)[f]
$\delta 3$	Impact of birth rate on new strays	0.11 (author's estimate)[f]

[a] Certain parameters have been included in the model for completeness since they are potential population flows. However, their values do not impact the results of the model. Therefore they have been set to zero. In the case of D4 and D5, zero might also be the most realistic value.
[b] Many parameter values come from a regional survey conducted for the Capital Region of New York State. The survey covered Albany and Rensselaer Counties and was conducted by mail. One thousand surveys were sent with a response rate of approximately 40%.
[c] Very little data is available on the spay/neuter rate of the stray population. However, it is reasonable to assume that fewer people spay/neuter their dog who abandon their animal than do in the general population. It was assumed here that three times as many dogs in the stray population are not spayed/neutered than in the owned population (P1). Fortunately though the value of this parameter is not well known, it has very little impact on the model dynamics.
[d] In addition to a survey of the general public, data were collected from area shelters and rescuers, including public shelters, incorporated private no-kill shelters/rescue groups, and individual rescuers. All known sources in the region responded. This information was used to estimate many model parameters.
[e] On the basis of conversations with animal control personnel.
[f] With little available data, author's estimates of these parameters were used. Many of these parameters were approximated by assuming that the initial model dynamics of the model were stable (i.e., the numbers used were based on a combination of reasonability and the level that held the initial populations stable in the base scenario). In all cases, the sensitivity of the model to these parameters was tested.

when stray adoptions go up, this decrease only partially compensates for the increase in stray adoptions.

Using the inputs described above, a base case model was created. The population sizes and flows into and out of each population were stable over time in the base model. It should be noted that not only is the population size set to be approximately the estimated size from the survey, but also the flows approximate the levels found in the data. Approximately 5500 dogs go to shelters each year in the model. The size of each supply source (S2–S5) is also based on the survey findings. The estimated shelter adoption rate (S2) from the survey (about 2900) is close to the amount estimated from surveying local shelters (2600). S2 in the model is between these two estimates.

Since this model includes many parameters which must be estimated on the basis of incomplete information, the sensitivity of the model to these assumptions was tested. The model was found to be insensitive to most parameters, with only 3 of 36 parameters/time horizons having an elasticity of one or more in absolute value, indicating that a 1% change in most input variables causes less than a 1% change in output. In fact, half of the parameters/time horizon combinations had an elasticity less than 0.1 in absolute value. By far the most sensitive parameter in the model is the spay/neuter rate, with a 1% increase in the spay/neuter rate decreasing the death rate by 14% using the longer time horizon. Fortunately, the most uncertain variables (such as the dynamics of the stray population) tended to have low sensitivities, while the more sensitive variables tended to have more reliable data available. The time period used was also found to have a large impact on model results with half of the parameter elasticities changing sign when the time period was extended.

Treatments

The primary purpose of the model is to test the effects of various potential policy alternatives or "treatments" on dog euthanasia rates. Possible treatments that can be used to reduce euthanasia of dogs include low-cost spay/neuter programs, public relations programs to encourage spay/neuter behavior, public relations programs to encourage consumers to adopt animals rather than buying animals from sources that increase supply, financial incentives for adopting, taxes on purchases from other dog sources, improved marketing to increase shelter adoptions, public relations programs to encourage "responsible" ownership (i.e., discouraging abandonment and animal abuse/neglect even if it means discouraging some of these people from owning pets), and increasing shelter space.

RESULTS

Spay/Neuter Programs

Using the model structure, a reduction of 46.8% in the percentage of dog owners who do not spay/neuter their animal results in a region with dynamics similar to the New York State Capital Region being able to bring the number of dogs euthanized down to zero. In other words, if about half of the people who do not spay/neuter their animal could be convinced to change this behavior, such a region could become "no-kill" for the dog population. It should be noted that the euthanasia rate used here is the long-term steady-state value. This steady state can take a surprisingly long period of time to achieve. Time-scale issues will be discussed in more detail later.

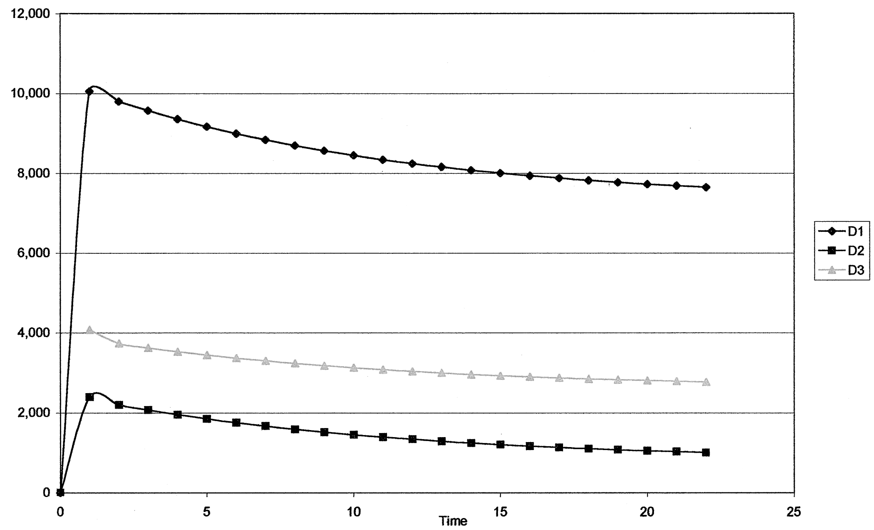

Fig. 2. Death rates over time with low-cost spay/neuter program.

Increasing spay/neuter levels shows diminishing returns. In other words, as more and more people spay and neuter their animal, additional increases in the spay/neuter rate show less benefit. Initial improvements to the spay/neuter rate show about twice as much benefit as the same amount of change as society approaches a "no-kill" goal. However, even as society approaches "no-kill" changes to the spay/neuter rate still have a powerful impact

Figure 2 gives a better understanding of the change in death rates over time. This graph shows not only the change in the euthanasia rate (D3), but also the effect of the spay/neuter rate on the death rate of strays (D2) and owned dogs (D1). As indicated, even after more than 20 years, the full impact of a one-time permanent increase in the spay/neuter rate is still being felt. In fact, though the chart does not extend this far, it takes approximately 40 years for the death rate to stabilize at its new level. A decrease of 27% in percentage of people not spaying/neutering their animal is used in this chart. This percentage was used because 27% of people surveyed who did not spay/neuter their animal said they would do so at a lower price. Therefore, this chart gives the potential impact of a subsidized spay/neuter program. This is a potential two-thirds reduction in the number of animals euthanized from a program giving financial incentives to spay/neuter dogs.

If we take the average cost of a spay/neuter procedure to be approximately $100 (Preece and Chamberlin, 1993), according to the survey results, the spay/neuter rate increases approximately linearly as the price of the

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procedure is reduced. From this information and regional demographic information, the impact per dollar spent on a spay/neuter program can be calculated. The cost-efficiency measure depends on what is assumed regarding human behavior. An assumption that minimizes the cost would be that the number of people using the spay/neuter program is exactly equal to the number of households in the marginal spay/neuter population (i.e., no "free-riders"). Using this "minimum" measure, the change in the average annual euthanasia rate per $1000 spent is 0.51% using a 10-year horizon and 1.08% using a 100-year horizon. But some people who would spay/neuter anyway would likely take advantage of the subsidized program. The "maximum" measure assumes that all consumers who have the option switch to the low-cost program, increasing the financial burden on that program. Using the "maximum" measure, the change in the average annual euthanasia rate per $1000 spent is 0.04% using a 10-year horizon and 0.08% using a 100-year horizon.

An alternative method to financial incentives for increasing spay/neuter rates is to conduct a public information campaign to encourage the people to spay/neuter their animal. Media campaigns for similar causes have been very effective at times on other issues. Since the results of such a campaign can vary greatly, the cost effectiveness cannot be estimated with great precision. However, we can arrive at a rough approximation. The information on the first three lines of Table II is adopted from Ad Resource (2000).

A conservative assumption would be that an effective campaign will need to use a mixture of media rather than simply the most cost-effective medium. A further conservative assumption used here is that the campaign reaches residents at random rather than being focused on a particular population. A well-targeted campaign may be able to reduce costs further by focusing on likely dog owners who may not spay/neuter their animal. Using these assumptions, the cost effectiveness for an education campaign appears to be in roughly the same range as the low-cost spay/neuter program. It should be noted that the cost of a subsidized spay/neuter program must be paid every year while a one-time education program could have long-lasting effects. Table III shows the cost effectiveness of an education program assuming different frequencies of the campaign.

Programs to Encourage Adoption

A second method for reducing euthanasia rates is to increase the adoption rate. It is important to recognize that adoption rates can be increased from two possible sources which have quite different long-term impacts. One way to increase adoption is through substitution of sources (i.e., people who would otherwise purchase their dog from a different source). The

Table II. Cost of Various Advertising Media (Source: Ad Resource, 2000. Final Row Calculated by Frank, J.)

	TV	Magazine	National newspaper	Radio	Banner Ads	Billboard
Average cost per 1000 impressions	$200	$60	$35	$50–$150	$34	$250
Average minimum spending requirement	$50,000	$10,000–$50,000	$10,000–$50,000	$2,000–$5,000 per month	$2500	$2000–$5000 per month
Average response rate	0.50%	0.25%	0.25%	0.50%	0.40%	N/A
Cost for one impression per household in region	$34,600	$10,380	$6055	$17,300	$5882	$43,250
Cost to achieve 2828 responses	$1,131,326	$678,796	$395,964	$565,663	$240,407	N/A

Table III. Percent Change in Average Annual Euthanasia Rate Per $1000 Spent

	10-year horizon	30-year horizon	100-year horizon
Once/3 years	0.091	0.149	0.191
Once/7.5 years	0.226	0.373	0.478
Once/15 years	0.453	0.747	0.957

other source of increased adoptions is the "marginal consumer," people who would not have purchased a dog at all if they had not been encouraged to adopt. If the adoption rate increases 90% through substitution, the region can sustainably reduce the number of dogs killed to zero using the model. This treatment shows approximately constant returns to scale with early improvements having the same impact as adoption changes as society is close to "no-kill."

The results for increasing adoption by new dog owners is dramatically different than the results for increasing adoption by substitution of sources. Using the euthanasia rate 100 years after treatment, the adoption rate would have to increase 656% using new dog owners to eliminate all euthanasia (compared to an increase of 90% for substitution of sources). Also the impact of the treatment is quite different depending on what time period is considered. Looking at the impact 1 year after treatment, euthanasia reaches zero when the adoption rate is increased close to 100%. However, looking at euthanasia after 30 years or after 100 years, the effort required to reach "no-kill" increases dramatically. Intuitively, this is because the number of pet owners has increased due to the higher adoption rate, which causes more abandonment and reverses much of the benefits of the increased adoptions. It should also be noted that returns to scale are close to constant.

If we use the same average response rate as for a spay/neuter campaign, Table IV below gives the change in the euthanasia rate per $1000 spent on an adoption campaign that assumes substitution and otherwise using the same assumptions and time period as in Table III.

As shown, the cost efficiency of the adoption program is somewhat lower than that of the spay/neuter campaign, particularly over time horizons of 30 years or longer.

An alternative method of promoting adoption is by using breeding restrictions to limit alternative sources of supply, or to place a tax on breeding.

Table IV. Percent Change in Average Annual Euthanasia Rate Per $1000 Spent

	10-year horizon	30-year horizon	100-year horizon
Once/3 years	0.075	0.076	0.076
Once/7.5 years	0.188	0.189	0.190
Once/15 years	0.376	0.378	0.380

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Because the social impact of a tax can be more readily analyzed, the impact of a tax is used as one option as well as a proxy for other options restricting supply sources that are substitutes for adoption. The cost of a tax can be estimated using the economic concept of producer and consumer surplus. On the basis of the results of the survey, a tax that brings the purchase price of a dog to $1500 could change the behavior of 38% of the relevant population so that they purchase their next animal from a shelter. However, over a $1000 tax is very high and most likely politically unfeasible. If we instead assume an after tax purchase price of $700, this would change the behavior of 24.7% of the relevant population (assuming actual behavior corresponds with reported behavior). According to the survey results, the average purchase price of a dog from a breeder was $412 and the average purchase price of a dog from a pet store was $474. Taking a weighted average of these gives an average purchase price of $427 which implies a tax of $273 per dog.

The benefit in terms of improved animal welfare can be calculated from the model. However, a more difficult question is the cost of this tax. There is no direct cost to the program (assuming administrative costs are low) since revenue is actually generated from the tax. However, there is a social cost in lost consumer surplus and lost producer surplus. Generally speaking, the consumer surplus represents the utility consumers receive from a good in excess of its price, while the producer surplus represents the profit received by the supplier of a good above the cost of production (for further discussion of the concepts of producer and consumer surplus see Hicks, 1943). **A6** Theoretically, the size of the producer and consumer surplus should take into account any negative economic effects of reducing or eliminating sales of dogs from breeders and pet stores.

Figure 3 is adapted from the data in the survey results section indicating how many people would switch to adopting dogs if the price of animals from other sources increased. The graph converts the data into a standard demand curve so that the consumer surplus can be determined. In addition to the downsloping demand curve segment, a flat line indicating the amount of the tax is shown. The lost consumer surplus is the area between points ABC. Approximating this area as a triangle gives a lost consumer surplus of $80,020. Other consumers outside of this triangular area do lose money from the tax, but the loss is a transfer rather than a deadweight loss.

Calculating the lost producer surplus is a more difficult matter since we do not have the data to construct a supply curve. In fact, there really is no way with the data currently available to accurately estimate producer surplus. For lack of a better method to estimate this value, producer surplus will be assumed to be approximately equal to consumer surplus, giving a very rough deadweight loss estimate for the tax program of $160,000.

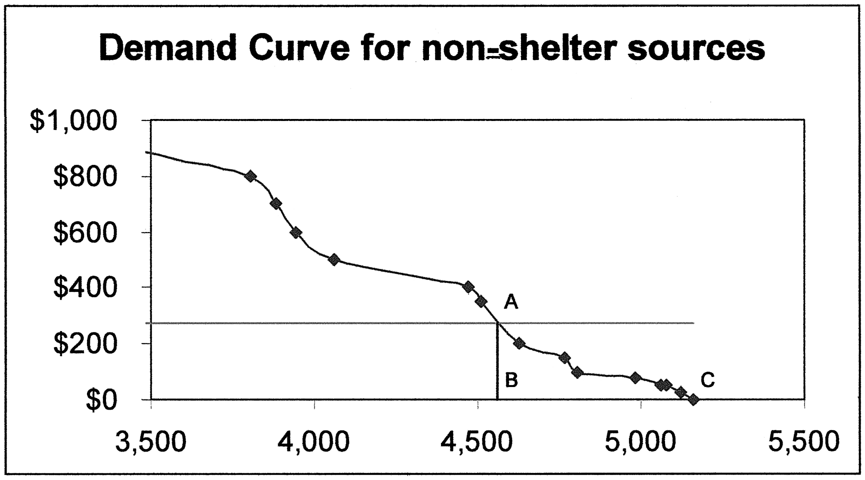

Fig. 3. Consumer surplus lost from a tax on dogs from nonshelter sources.

Since the result of this treatment is qualitatively the same as the public education program to increase adoption (i.e., both programs would cause people to substitute adoptions for other dog purchases), the cost effectiveness of these two programs can be compared directly without recreating the welfare impacts of this treatment. The cost of the public education program is estimated to be approximately $25.56 per adoption generated while the social cost of the tax is only $9.91 per adoption generated.

Reducing Abandonment

One final approach a public education campaign could take is to focus on reducing abandonment rather than adoptions or spay/neuter behavior. The campaign would educate people regarding the serious decision involved in taking on a pet, make more tangible the suffering and death caused by animal abandonment, and encourage people not to take on dog ownership unless they understand the costs, responsibilities, and time involved.

Figure 4 indicates the reduction in the abandonment rate required to eliminating the killing of dogs. A campaign to encourage dog purchasers to be responsible and think hard before making a purchase may actually reduce dog purchase rates as well as abandonment rates. However, in this graph abandonment was assumed to be reduced without changing the number of dogs purchased. As in Fig. 3 because of widely varying effects over different time horizons, the euthanasia rate is shown for 1, 30, and 100 years.

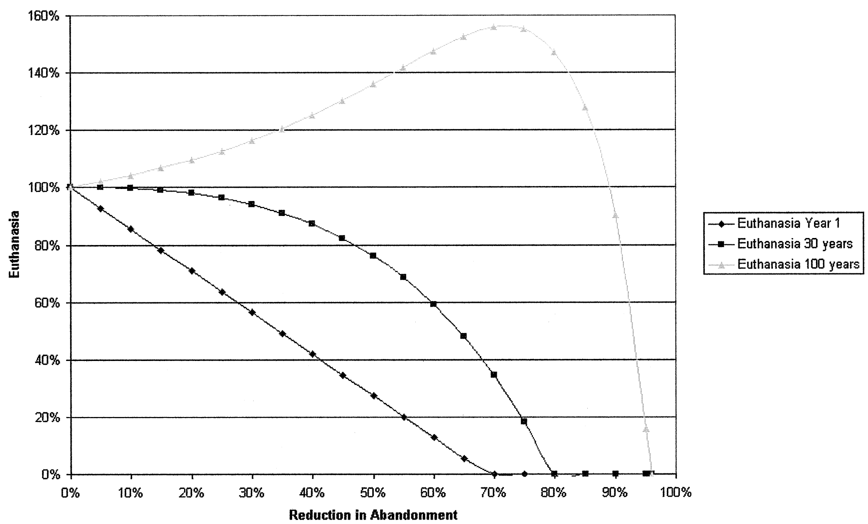

Fig. 4. Effect of reducing abandonment in isolation on euthanasia.

As indicated, the abandonment rate must be reduced about 70% to stop euthanasia in 1 year. However, abandonment rates must be reduced 96% to keep the euthanasia level at zero for 100 years. But the most interesting part of the graph is the shape of the curve as the time horizon changes. At a 100-year horizon, euthanasia sharply goes up before it declines. This is due to a sharp dog population increase that occurs under the assumptions used in this treatment. It was assumed under this treatment that birth rates (per dog), pet purchases, and adoptions remain stable even though abandonment rates go down. Therefore, the dog population increases and the number of dogs abandoned increases in some cases even though the abandonment rate goes down.

Using the same general assumptions as used in the spay/neuter and adoption campaigns already discussed, Table V gives the cost efficiency of a campaign stressing responsible ownership/guardianship in order to reduce abandonment.

Table V. Cost Effectiveness of Reducing Abandonment

	10-year horizon	30-year horizon	100-year horizon
Once/3 years	0.075	0.076	0.076
Once/7.5 years	0.034	0.033	0.031
Once/15 years	0.015	0.014	0.013

Synergies

Although we have analyzed the effect of a variety of treatments individually, an interesting and important question is what effect combining treatments has on euthanasia rates (i.e., are there synergies or possibly reduced effectiveness when combined). This question can be answered by using the economic concept of a production possibilities frontier (PPF). A PPF curve shows all the combinations of two inputs that can be used to achieve a certain level of output. PPF curves were created for different pairs of treatments. A goal of reducing euthanasia by 50% over a 30-year horizon was chosen to calculate the PPF. Figure 5 shows the PPF curve for different levels of improvements in spay/neuter rate and adoption rates.

The axis for adoption indicates the percent increase in the adoption rate from its starting level. Adoption is assumed to be through substitution in all the PPF curves. The spay/neuter axis indicates the percentage decrease in the number of people not spaying/neutering their dog. The dotted curve is a straight line, while the actual data (solid curve) plots slightly below this line, indicating that fewer resources are required in combination than when the two treatments are done separately. In other words, there are some synergies when the two treatments are combined.

However, the other two PPF curves show the opposite situation. Figure 6 shows spay/neuter combined with reduced abandonment. The abandonment

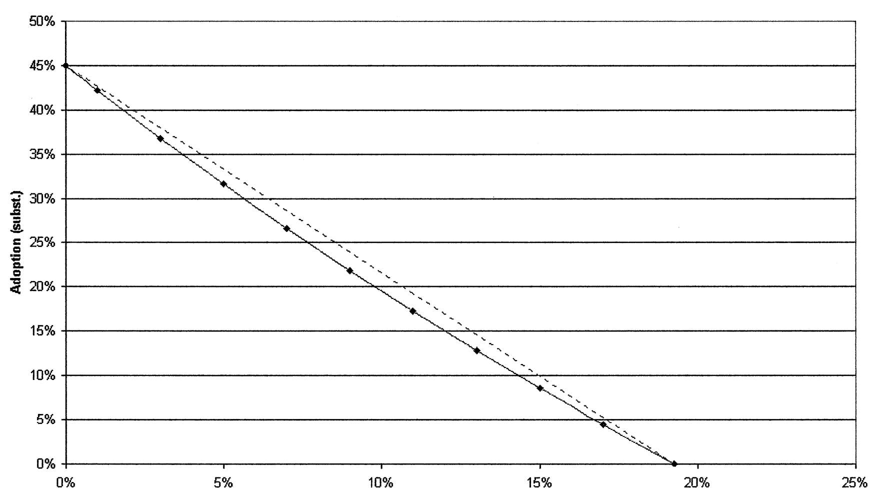

Fig. 5. Production possibilities frontier for adoption through substitution vs. spay/neuter.

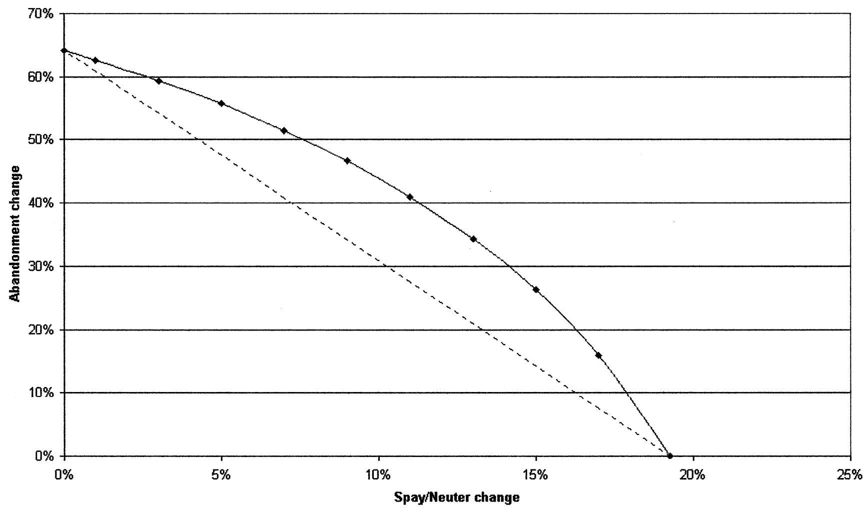

Fig. 6. Production possibilities frontier for abandonment vs. spay/neuter.

axis indicates the percentage reduction in abandonment rates. For the sake of consistency with the prior "no-kill" simulation, it was once again assumed that abandonment rates were reduced without affecting other model variables. The curve lies above the straight dotted line, indicating that more resources are required when the two treatments are done in combination than when they are done separately. Somehow, these two treatments hamper each other's effectiveness.

Finally, Fig. 7 shows abandonment and adoption treatments in combination. Once again, the actual data lie above the dotted line indicating that these two treatments also hamper each other's effectiveness when combined.

Time-Scale Issues

Often, fairly long time horizons have been utilized here to address the question of sustainability and long-term steady state. However, a very important question to a community or organization that decides to spend a large amount of money on an effort to address the surplus dog population problem is how long they need to wait for the treatment to show full effectiveness. Once again using the simple goal of reducing euthanasia rates, Fig. 8 shows how the euthanasia rate changes over time for various treatments. The level of each treatment is chosen to create a 50%

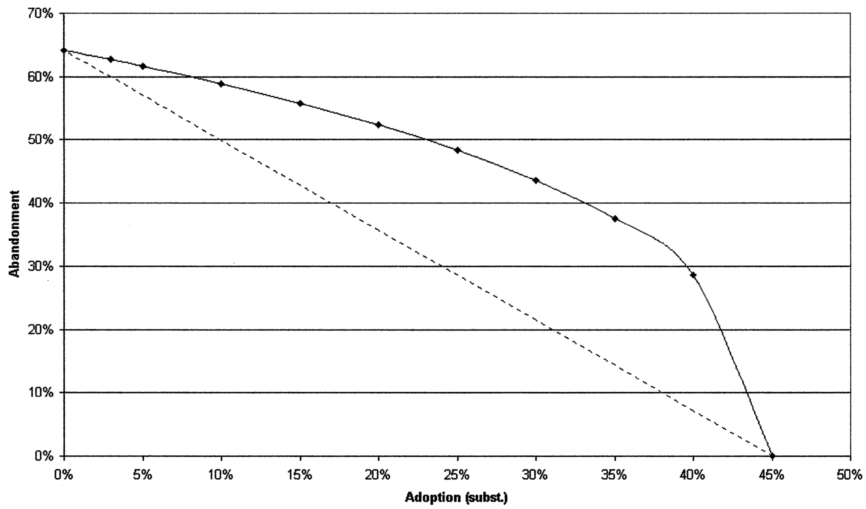

Fig. 7. Production possibilities frontier for abandonment vs. adoption through substitution.

reduction in euthanasia rates (compared to the before-treatment rate) after 30 years.

Figure 8 shows that the spay/neuter treatment benefits occur gradually, and stabilize given this level of treatment after about 40 years. Increasing

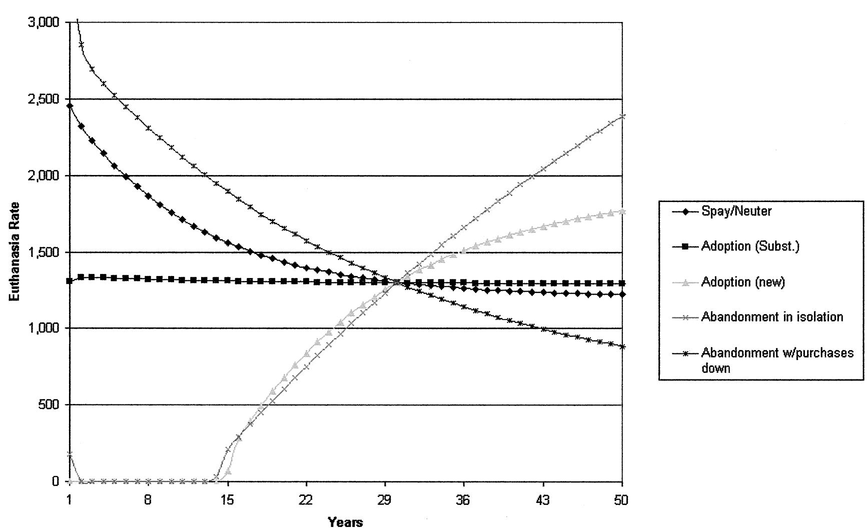

Fig. 8. Impact of various treatments over time.

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adoption rates through substitution shows immediate and permanent benefits, with only a slight change over time. Adoption by adding new dog owners also shows immediate benefits. However, this benefit decreases over time as the dog population rises. Eventually, the benefit appears to stabilize at a new reduced level. Decreasing abandonment rates also shows immediate benefits if it is assumed that this variable can be changed in isolation. However, these benefits disappear as the dog population rises. On the other hand, if we assume that abandonment can only be reduced by deterring likely abandoners from purchasing dogs and we assume two-dog purchasers must be deterred to eliminate one abandonment, then the abandonment treatment has exactly the opposite pattern over time. Initially, the euthanasia rate is high (this is due to adoptions going down along with other sources of animal supply). However, this euthanasia rate goes down rapidly, and eventually becomes the lowest of all treatments on the graph.

DISCUSSION

In general, spay/neuter was found to be the most effective single method of addressing overpopulation, particularly over long time horizons. This was found to be true both for education and for low-cost spay/neuter programs.

However, it is important to note that the results here depend on many assumptions. All the campaigns are assumed to have the same response rate. However, in reality these campaigns will have varying response rates. Although a spay/neuter campaign appears to be the most effective method for a given response rate, it is possible that the public would be more responsive to an adoption campaign. Although there is still misinformation and ignorance about spaying/neutering animals, the public is generally more aware of the importance of spaying/neutering than they are aware of the connection between their animal purchase choices and euthanasia rates. In addition, while the spay/neuter choice is usually well thought out, dog purchases are sometimes impulse decisions, which may be more easily affected through marketing efforts. It should also be noted that though a public education campaign promoting adoption and a marketing campaign focusing on the product are quite distinct in practice, for purposes of the theoretical model, the results are identical since the same response rate is assumed.

It is also important to note that this is a simplified model and does not take into account some issues. For example, there may be factors that hinder the adoptability of certain animals. In effect, the model assumes that it is simply an imbalance of supply and demand that prevents animals from getting adopted. In reality, some percentage of animals will have medical or behavioral issues that will make adoption difficult or impossible regardless of the number of available homes. Therefore, the concept of reducing the number of dogs killed to zero is an oversimplification.

With these caveats in mind, the model results do clearly indicate that spay/neuter programs are an important component, and probably the most effective component, of an effort to reduce dog overpopulation. The "minimum" and "maximum" measures of subsidized spay/neuter program effectiveness vary considerably, emphasizing the importance of eliminating "free-riders" from using these services. Many actual subsidized spay/neuter programs in place do require some kind of proof of low-income (such as Medicaid eligibility) to participate, others target certain communities. The literature previously cited also suggests that most people choose not to use a subsidized spay/neuter service even when it is offered, suggesting that the free-rider problem may be limited. Not only are spay/neuter efforts the most powerful, but they also grow in strength over long horizons and combine well with adoption efforts.

Although adoption appears to be less effective over long horizons than spay/neuter efforts, it still can be quite effective. There are several methods that could be utilized to increase adoption rates. The first is to educate the public in the same way that one would with a spay/neuter education campaign. Many consumers make their animal purchase decision without an awareness of the impact their choice of purchase source has on the dog population. Making the public aware of the consequences of their choice could have a powerful impact. A second approach that can be taken through the media is to focus on marketing the product rather than on an altruistic message. This can be done by aggressively advertising animals for adoption, both through the media and through events and appearances. A third method of encouraging adoption is through financial incentives. Theoretically this could be through subsidies for adoption or taxes on dogs from other sources. However, there are problems with reducing the price of adopted dogs. First, lower purchase prices have been associated with higher abandonment rates (Patronek *et al.*, 1996). Second, dogs that are too cheap or free can be purchased for illicit purposes such as to resell for research or for other abusive uses. In addition, subsidies require funding while taxes can generate public funds. Therefore, the mechanism most often discussed for financial incentives is taxes rather than subsidies.

An alternative to taxes would be restrictions on the breeding market that act to limit this source of supply. Many animal shelters are proposing legislation to ban or restrict the breeding of companion animals in their communities and states (Rowan, 1992). This is opposed by animal breeders, since it directly impacts on their livelihood. On the surface, the tax appears more efficient than a public education effort regarding adoption, however this assumes that the administrative costs of the tax are minimal, that it is enforceable, and that it is politically feasible. These are actually quite strong assumptions, particularly regarding enforceability of a tax.

A campaign to reduce abandonment was generally found to be less cost-efficient than the other options already discussed. However, two caveats must be stressed. First, as previously mentioned, all types of campaigns are assumed to have the same response rate. Since a generic campaign response rate has been assumed here, the actual relative cost efficiency may be higher or lower depending on the public's responsiveness to this type of campaign. Second, it should be noted that a campaign to encourage responsible ownership may have other positive effects outside of changing the euthanasia rate, such as an improvement in quality of life for dogs.

CONCLUSION

These results demonstrate that there are several cost-effective methods of reducing dog overpopulation. Spay/neuter campaigns are the most powerful over long time horizons. Cost-effective numbers are shown here because they allow a common unit for the comparison of programs. It must be noted however that these cost-effective numbers are rough estimates at best, and are best interpreted as level-of-magnitude estimates of costs rather than precise forecasts, since public responsiveness and a number of other key variables are not known with certainty. Well-monitored pilot programs would be the ideal method for testing these costs. This research provides valuable information to such programs by giving information on what programs are likely to be most effective.

This research also provides valuable information for evaluating such programs. For example, since spay/neuter programs can take over 30 years to reach full effectiveness, actual efforts to measure the full effectiveness of such programs often will underestimate the long-term impact. Spay/neuter evaluations must be done with very long lags or at least done in such a way as to extrapolate future impacts.

The results here also counter the arguments made by some veterinarians that spay/neuter programs are ineffective because they only reach a small percentage of the population. In fact, because of the powerful impact of birth rates on population dynamics, even a small change in birth rates can make a dramatic difference in long-term euthanasia rates.

Despite the caveats regarding cost measures being approximate, they still do give a rough idea of what it would take to get to a "no-kill" society on a regional basis. Comparing these numbers to community willingness-to-pay measures for the Capital Region in New York (Frank, 2001), the costs are generally a level of magnitude lower than society's willingness to pay, at least for this region. Therefore, even with rough numbers it is safe to say that "no-kill" is achievable for a cost acceptable to society. In other words, if we view dog overpopulation from purely a human perspective, the benefits for humans of reducing dog overpopulation outweigh the costs to humans of reducing dog overpopulation.

Although these estimates still rely on a number of assumptions, the nonmonetary measures of what it takes to reach no-kill from the model are known with a higher degree of certainty. For example, knowing that it takes a 47% change in the number of people who do not spay/neuter their dogs or a 90% increase in the adoption rate to reach no-kill for a region with certain demographic characteristics can benefit decision makers by improving long-term planning and goal-setting for a campaign aimed at reducing companion animal overpopulation.

As more and more humans express concern regarding dog overpopulation and increasing numbers of nonprofit organizations work to achieve a no-kill society, it is important to understand how various programs interact and how their effectiveness changes over time. On this front, it appears that increasing adoption or spay/neuter rates fares better than focusing on reducing abandonment. In fact, it is encouraging to note that adoption and spay/neuter programs appear to work better when done together.

The results here also highlight the importance of issues that often are not considered. When setting goals or measuring results, time-scale is key and must be given careful consideration. When planning adoption programs, in terms of long-term animal population dynamics, *who* adopts makes a difference. In addition, if efforts are made to discourage abandonment, reducing abandonment rates without reducing birth rates can actually lead to more euthanasia long-term due to a growth in the animal population.

In order to draw realistic conclusions from the model, data from a particular U.S. region were obtained. However, this does not imply that the results here cannot be generalized to the communities across the United States or internationally. Although the precise quantitative parameters will of course vary, many of the qualitative conclusions of this study are applicable to a wide range of communities.

Dog overpopulation is a human problem, with human costs and deriving from human sources. The dynamics of the problem also depend primarily on human behavior and population dynamics. It also is a problem that can only be addressed through human solutions. However, the good news is that there are adequate and cost-effective solutions, and these solutions have more human benefits than human costs.

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