Solving Stray-Animal Problems by Economic Policies

Liu, Shi-Miin and Hsiao-Chi Chen*

Abstract

This paper investigates optimal economic policies, that deal with stray animals. We construct a two-stage game to characterize the interactions among the regulator, pet shops, and consumers. In particular, we employ a simple Hotelling (1929) model to endogenize the behaviors of dog/cat purchasers and adopters and show that the regulator may tax or subsidize pet-animal buyers if it aims to maximize social welfare in an imperfectly competitive pet-animal market. On the other hand, taxing pet-animal buyers is the regulator's best choice in a perfectly competitive pet-animal market. These results hold under both linear and quadratic breeding-cost and strays' environmental-damage functions. By contrast, when the regulator is targeting to minimize the number of stray animals, taxing dog/cat buyers is the best choice. This outcome holds whether the pet-animal market is perfectly or imperfectly competitive and whether the breeding-cost and strays' environmental-damage functions are linear or quadratic.

Keywords: Stray Animals, Externality, Tax, Subsidy, Perfect Competition, Imperfect Competition

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1. Introduction

Many problems are encountered yet ignored in our daily lives. Stray dogs/cats are one of them. Because having no spending power and voting right, the strays usually have the least priority in the welfare concerns of the human societies. However, neglecting stray animals not only makes people suffer emotionally, but also causes financial and human-life losses. In analyzing whether adoption and low-cost spay/neuter programs are effective in reducing overpopulation of companion animals, Frank and Carlisle-Frank (2007) offer three possible utility-based reasons to minimize unwanted dogs/cats. The first one is the direct expense resulting from dog bites, traffic accidents due to evading the strays, barking noises, sanitary concerns, and other nuisances. Relevant studies using U.S. data include Sosin et al. (1986), Sacks et al. (1996), Clifton (2002), Baetz (1992), etc. The second reason is the indirect personal pain caused by observing the plight of these pitiful animals. People thus support animals' protection and their welfare by donating money (Jasper and Nelkin, 1992) or writing letters to Congressmen to urge relevant legislation (Fox, 1990). The third reason is obviously the distress of stray dogs/cats themselves. If their sufferings and deaths can be measured economically, this cost, we agree with Frank and Carlisle-Frank (2007), would probably be the greatest among the three categories.

People can discuss, explore, and propose solutions for stray-animal problems from several respects. The simple catch-and-kill programs employed by many countries are proven un-successful; otherwise most of the stray-animal problems should have disappeared. Moreover, these programs cause huge bitterness for both the strays and people who care for them. Therefore, other ways to control the number of the strays and/or to make them have better chances to be treated well are certainly needed. Because financial incentives usually have the greatest impact on human behaviors, economic means are anticipated to be the most effective methods to lessen or to solve the stray-animal problems. For instance, subsidized spay/neuter programs are promoted by many local governments. Although the usefulness of these programs in controlling animal populations is arguable (e.g., MacKay, 1993; Rush, 1985), some researchers (e.g., Frank, 2001) think that the spay/neuter techniques have a powerful impact on long-term population sizes even though the participation rate of pet owners is unsatisfactory. Another example is utilizing resources efficiently to educate people such that their companion animal euthanasia can be reduced (Frank, 2002). Then, sizes of the strays could decrease due to less abandoning. The developed countries value human as well as animal lives through ideas broadcasting and budgets planning. For instance, animal policemen/ policewomen in the U.S. are responsible for charging animal-abuse cases and rescuing the vulnerable. Hence, how animal rights are protected and how the stray-animal problems are dealt with can reflect whether a society is progressive. To really care for animal welfare and the safety of human societies, current efforts are still insufficient even in the developed countries. Therefore, more influential and effective policies having economic consequences should be adopted by governments.

It is well known in the economic literature that the Pigouvian tax is effective in correcting negative externalities caused by agents' activities. Thus, this paper tries to explore whether a policy of taxing or subsidizing consumers' purchases of pet animals can control the problems of stray animals. We will examine the effectiveness of this policy based on two criteria: to maximize the social welfare and to minimize the number of stray animals. The latter is equivalent to minimizing the environmental damage caused by the strays. A game theoretical model considering the regulator, pet shops, and consumers is used to find the optimal policy. We hope that this bigger picture and ambition can actually make a difference and a contribution, especially when relevant studies are so few.

We construct a two-stage game to characterize the interactions among the regulator, pet shops, and consumers. In the first stage of the game, the regulator chooses to subsidize or tax the purchases of companion animals. Then, consumers decide to buy or adopt dogs/cats, and pet shops choose their optimal pet-animal amounts for sale in the second stage of the game. Afterwards, the perfectly or imperfectly competitive pet-animal market is cleared. We use a simple Hotelling (1929) model here to endogenize the behaviors of dogs/cats purchasers and adopters. Our results show that pet-animal buyers should be taxed or subsidized, if the regulator aims to maximize the social welfare in an imperfectly competitive pet-animal market. On the other hand, when the pet-animal market is perfectly competitive, the regulator should tax dogs/cats buyers. These results hold under both linear and quadratic breeding-cost and/or strays' environmental-damage functions. By contrast, when the regulator aims to minimize the number of stray animals or the environmental damage caused by them, taxing dogs/cats buyers is the only optimal policy. This outcome holds under perfectly and imperfectly competitive pet-animal markets as well as under linear and quadratic breeding-cost and strays' environmental-damage functions.

The Hotelling model has been widely applied in many fields, such as environmental economics (e.g., Stevens, 2013; Okullo et al., 2015), industrial organization (e.g., Tabuchi, 2012; Colombo, 2013), international trades (e.g., Roy and Saggi, 2012), and political economics (e.g., Dziubiński and Roy, 2013; Xefteris, 2016). This study is also an application of the Hotelling model. Different from the existing works, we consider environmental damages caused by stray animals in the social welfare functions, and allow distinct market structures for pet animals. Accordingly, our contributions are in two respects. First, to the authors' knowledge, this paper is the first using economic models to investigate stray-animal problems. Second, our results offer the regulators in different countries an effective economic means to manage their stray-animal problems.

The rest of this paper is structured as follows. Section 2 presents the model. The equilibria under both the imperfectly and perfectly competitive pet-animal markets are derived in Section 3. Then, the robustness of our results is examined in Section 4. Finally, our conclusions are drawn in Section 5.

2. The Model

We use a simple Hotelling (1929) model to characterize the behaviors of dogs/cats purchasers or adopters. Let the animal consumers with a population size normalized to one distribute uniformly over a unit location interval $[0,\ 1]$. To simplify the analyses, we assume that the consumers have no outside options of not getting a pet, and that each of them can own one dog/cat only.[1] Accordingly, each consumer either buys a dog/cat from a pet shop or adopts it from an animal shelter or street. Suppose that all pet shops are located at end-point 0, and shelter and street dogs/cats are located at end-point 1. There are $\bar{Q} > 1$ strays in animal shelters and on streets, which is exogenous in this model. If a consumer located at point $y \in [0,\ 1]$ buys? a dog/cat from a pet shop, she/he will have utility

$$U_y = h_0 - c_0 y - t - p, \tag{1}$$

where $h_0 > 0$ is the happiness level from buying a dog/cat, $c_0 y$ is the cost to raise the purchased pet, t is the taxes ($t > 0$) paid to or the subsidies ($t < 0$) obtained from the regulator, and p is the purchase price of the dog/cat. The closer is the consumer located to the pet shop (i.e., smaller y), the lower raising cost has the consumer because he/she is more willing to take care of the purchased dog/cat. In contrast, if

[1] In a Hotelling model, Böckem (1994) assumes that each consumer has an individual reservation price for the product he wants due to having an outside option. Then, Böckem (1994) shows that the maximum differentiation result proved by d'Aspremont et al. (1979) no longer holds. Our results will change if pet consumers are allowed to have outside options, because our demand function for pet animals will change under the set-up of Böckem (1994).

consumer y adopts a dog/cat from an animal shelter or street, she/he paying nothing will have utility

$$U_y = h_1 - c_1(1-y), \tag{2}$$

where $h_1 > 0$ is her/his happiness level and $c_1(1-y)$ is the cost to raise the adopted dog/cat. The closer is the consumer located to the animal shelter (i.e., smaller $(1-y)$), the lower raising cost has the consumer because he/she is more willing to take care of the adopted animal. Unequal values of h_0 and h_1 will reflect distinct happiness levels through buying and adopting dogs/cats. Also, we allow different values of c_0 and c_1 to represent distinct raising costs for a purchased pet and a stray. Or, one can regard c_0 and c_1 as consumers' idiosyncratic preferences over pet shops and animal shelters (or street dogs/cats), respectively. The larger is c_0 (c_1), the less a consumer is willing to take care of a dog/cat from pet shops (animal shelters or street dogs/cats).

By making U_y's in (1)-(2) equal, we get that a consumer located at x is indifferent between purchasing and adopting a dog/cat due to

$$h_0 - c_0 x - t - p = h_1 - c_1(1-x) \Leftrightarrow x = \frac{h_0 + c_1 - h_1 - t - p}{(c_0 + c_1)}.$$

To have $x \in (0,\ 1)$, we impose condition

$$h_1 - c_1 + t + p < h_0 < h_1 + c_0 + t + p. \tag{3}$$

This condition suggests that the consumer's happiness from buying a pet animal cannot be too large or too small. If h_0 is too large, no one will adopt strays. On the other hand, the pet-animal market would disappear if h_0 is too small. Obviously, these extreme cases are not consistent with the real world situations. Then, we have the demand function for pet shops,

$$x = \frac{h_0 + c_1 - h_1 - t - p}{(c_0 + c_1)}, \tag{4}$$

and the demand function for strays in animal shelters and on streets is

$$1 - x = \frac{h_1 + c_0 + t + p - h_0}{(c_0 + c_1)}. \tag{5}$$

Accordingly, the total consumer surplus of having a dog/cat by (4) and (5) equals

$$\begin{aligned} CS(p,\ x) &\equiv \int_0^x (h_0 - c_0 y - t - p)dy + \int_x^1 [h_1 - c_1(1-y)]dy \\ &= h_1 - \frac{c_1}{2} + x[h_0 + c_1 - h_1 - t - p] - \frac{x^2}{2}(c_0 + c_1). \end{aligned} \tag{6}$$

We presume that pet shops provide identical animals at a constant marginal cost $\bar{c} > 0$. The pet-animal market can be perfectly or imperfectly competitive. Given pet-animal demand x in (4), we can derive the associated equilibrium price (p^*), equilibrium amount of pet animals (x^*), and producers' surplus (π^*) for all pet shops in a perfectly competitive market. In contrast, we use $\hat{p}$, $\hat{x}$, and $\hat{\pi}$ to denote the equilibrium price, the equilibrium amount of pet animals, and producers' surplus for all pet shops in an imperfectly competitive market. Equilibria ($\hat{p}$, $\hat{x}$, $\hat{\pi}$) and (p^*, x^*, π^*) will be derived in Sections 3.1 and 3.2, respectively.

Next, we define the social welfare function, SW, as the sum of consumers' surplus, producers' surplus, tax revenues and the negative externality value caused by stray animals. Precisely, we have

$$SW = \begin{cases} CS(p^*,\ x^*) + \pi^* + tx^* - d[\bar{Q} - (1 - x^*) + r_0 x^* + r_1(1 - x^*)] \\ \qquad \text{in a perfectly competitive market,} \\ CS(\hat{p},\ \hat{x}) + \hat{\pi} + t\hat{x} - d[\bar{Q} - (1 - \hat{x}) + r_0 \hat{x} + r_1(1 - \hat{x})] \\ \qquad \text{in an imperfectly competitive market,} \end{cases} \tag{7}$$

where r_0 and r_1 are the probabilities of consumers' abandoning their dogs/cats after buying and adopting them, respectively;[2] and $[\bar{Q}-(1-x^*)+r_0x^*+r_1(1-x^*)]$ and $[\bar{Q}-(1-\hat{x})+r_0\hat{x}+r_1(1-\hat{x})]$ are the numbers of stray animals in the society at the end of the period. Here parameter $d>0$ represents the marginal environmental damage and distress caused by stray animals. We will first analyze a linear environmental damage. Then, a quadratic damage function will be discussed in the extension section. Moreover, no behavioral assumption on animal shelters is imposed in our models, because the main purpose of the shelters is to provide caring for abandoned pets and to coordinate their adoptions. In most countries, animal shelters are run by (local) governments. Thus, the shelters are very likely to pursue the goal of minimizing stray-animal numbers, which will be considered in Section 4.1. Furthermore, running shelters incurs costs. If the costs are linear functions of stray-animal numbers, i.e., $q\bar{Q}$ with q the marginal cost of taking care of a stray dog/cat, then our results will remain true qualitatively.[3]

Based on the above, a two-stage game is constructed to characterize the interactions among the regulator, consumers, pet shops, and animal shelters. In the first stage of the game, the regulator announces a tax or a subsidy to maximize the social welfare. Given the tax or subsidy, consumers decide to purchase dogs/cats from pet shops or to adopt them from shelters or streets, and then pet shops decide their optimal amounts of pet animals for sale in the second stage of the game. The pet-animal market is then cleared. Since our game has complete

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2 Here we assume implicitly that abandoning probabilities r_0 and r_1 are independent of h_0 and h_1. Owners' abandoning their pets is often caused by random and unavoidable reasons, such as their sickness, death, moving, and unemployment, or health conditions of their pets. Thus, r_0 and r_1 may not be affected by h_0 and h_1. On the other hand, the abandonment may be due to consumers' bounded rationality and their ignoring its consequences. We thank one referee for proposing this question. Thus, we have the chance to justify it.

3 Under the circumstance, the social welfare will become $SW=CS(p^*,\ x^*)+\pi^*+tx^*-q\bar{Q}-d[\bar{Q}-(1-x^*)+r_0x^*+r_1(1-x^*)]$ if the pet-animal market is perfectly competitive. Since $q\bar{Q}$ is a constant, it is easy to see that our results still hold. However, the equilibrium social welfare will become lower.

information, its subgame perfect Nash equilibria (hereafter SPNEs) can be derived by the backward induction method as follows.

3. Equilibria under Different Market Structures

The SPNEs under imperfectly and perfectly competitive pet-animal markets are derived in the ensuing subsections.

3.1. An Imperfectly Competitive Pet-Animal Market

Here we consider a Cournot oligopoly market with J, $J \geq 2$, identical pet-animal shops. Given the regulator's tax or subsidy choice t, we first derive the optimal behaviors of consumers and pet shops. Suppose these shops having the same cost function $c(q^j) = \bar{c}q^j$, $j = 1, 2, \ldots, J$. Given the inverse demand function for pets, $p = (h_0 + c_1 - h_1 - t) - (c_0 + c_1)(\sum_{j=1}^{J} q^j)$ implied by (4), firm j's profit function is

$$\pi^j = [(h_0 + c_1 - h_1 - t) - (c_0 + c_1)(\sum_{j=1}^{J} q^j)]q^j - \bar{c}q^j, \ j = 1, 2, \ldots, J,$$

where $h_0 + c_1 - h_1 - t > \bar{c}$ is needed. Applying the standard arguments used in the Cournot model, we can get all shops supplying the same amount of pet animals at equilibrium, i.e.,

$$\hat{q}^1 = \hat{q}^2 = \cdots = \hat{q}^J = \hat{q} = \frac{h_0 + c_1 - h_1 - t - \bar{c}}{(c_0 + c_1)(J + 1)} > 0. \tag{8}$$

Accordingly, the equilibrium price of pet animals equals

$$\hat{p} = \frac{h_0 + c_1 - h_1 - t + J\bar{c}}{(J + 1)}, \tag{9}$$

the equilibrium amount of pet animals is

$$\hat{x} = J\hat{q} = \frac{J(h_0 + c_1 - h_1 - t - \bar{c})}{(c_0 + c_1)(J + 1)}, \tag{10}$$

by (8), and the equilibrium total profit of the J shops is

$$\hat{\pi} = J[\hat{p} - \bar{c}]\hat{q} = \frac{J(h_0 + c_1 - h_1 - t - \bar{c})^2}{(c_0 + c_1)(J+1)^2}. \tag{11}$$

Given $(\hat{p},\ \hat{x},\ \hat{\pi})$ in (9)-(11), the regulator's social welfare function in (7) becomes

$$\begin{aligned} SW &= CS(\hat{p},\ \hat{x}) + \hat{\pi} + t\hat{x} - d[\bar{Q} - (1-\hat{x}) + r_0\hat{x} + r_1(1-\hat{x})] \\ &= h_1 - \frac{c_1}{2} + \hat{x}(h_0 + c_1 - h_1 - \bar{c}) - \frac{(\hat{x})^2}{2}(c_0 + c_1) \\ &\quad - d[\bar{Q} - 1 + r_1 + \hat{x}(1 + r_0 - r_1)]. \end{aligned}$$

Next, given $\hat{p}$ and $\hat{x}$, the regulator will choose $\hat{t}$ to maximize the social welfare defined in the above equation. The associated first-order and second-order derivatives are respectively

$$\begin{aligned} \frac{\partial SW}{\partial t} = \frac{-J}{(c_0 + c_1)(J+1)^2}&[h_0 + c_1 - h_1 - \bar{c} + Jt \\ &-d(1 + r_0 - r_1)(J+1)] \end{aligned} \tag{12}$$

and

$$\frac{\partial^2 SW}{\partial t^2} = \frac{-J^2}{(c_0 + c_1)(J+1)^2} < 0. \tag{13}$$

Equation (13) implies that the social welfare is a strictly concave function of t. Hence solving $\partial SW/\partial t = 0$ in (12) will give us optimal $\hat{t}$,

$$\hat{t} = \frac{d(1 + r_0 - r_1)(J+1) - (h_0 + c_1 - h_1 - \bar{c})}{J}.$$

At $(\hat{p},\ \hat{t})$, condition (3) can be reduced to

$$\begin{aligned} h_1 + \bar{c} - c_1 + d(1 + r_0 - r_1) &< h_0 \\ &< h_1 + c_0 + \bar{c} + d(1 + r_0 - r_1). \end{aligned} \tag{14}$$

Under condition (14), we have $\hat{x} > 0$ and $\hat{p} > 0$.[4] These results are summarized below.

Proposition 1.

Suppose the condition in (14) holds. Then the SPNE under an imperfectly competitive pet-animal market is

$$\hat{t} = \frac{d(1 + r_0 - r_1)(J + 1) - (h_0 + c_1 - h_1 - \bar{c})}{J} \geq (\leq)\ 0$$

iff $h_0 + c_1 \leq\ (\geq)\ h_1 + \bar{c} + d(1 + r_0 - r_1)(J + 1)$,

$$\hat{x} = J\hat{q} = \frac{1}{(c_0 + c_1)}[(h_0 + c_1 - h_1 - \bar{c}) - d(1 + r_0 - r_1)] > 0, \text{ and}$$

$$\hat{p} = \frac{1}{J(J + 1)}[(h_0 + c_1 - h_1 + \bar{c}(J^2 - 1)) - d(1 + r_0 - r_1)(J + 1)] > 0.$$

Proposition 1 gives the conditions under which the regulator will tax or subsidize dogs/cats buyers. When the happiness from purchasing dogs/cats (h_0) or the cost of raising adopted strays (c_1) is large, it is optimal for the regulator to subsidize purchasers of dogs/cats to enhance consumers' and producers' surpluses. In contrast, if the happiness from raising adopted strays (h_1), the cost of breeding dogs/cats ($\bar{c}$), the marginal damage caused by strays (d), the probability of abandoning purchased dogs/cats (r_0), or the number of pet-animal shops (J) is large, or the probability of abandoning the adopted strays (r_1) is small, then the regulator should tax purchasers of dogs/cats to raise the social welfare.

Moreover, optimal $\hat{t}$ has the ensuing properties.

Corollary 1.

Suppose the condition in (14) holds. Under an imperfectly competitive pet-animal market with linear costs, we have

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[4] Condition $h_0 > h_1 + \bar{c} - c_1 + d(1 + r_0 - r_1)$ suggests $\hat{x} > 0$, while $\hat{p} > 0$ is implied by $h_0 + c_1 - h_1 - \hat{t} + J\bar{c} > h_0 + c_1 - h_1 - \hat{t} - \bar{c} > 0$ based on (14).

(i) $\frac{\partial \hat{t}}{\partial h_1} = \frac{1}{J} > 0$, $\frac{\partial \hat{t}}{\partial \bar{c}} = \frac{1}{J} > 0$, $\frac{\partial \hat{t}}{\partial d} = \frac{(1+r_0-r_1)(J+1)}{J} > 0$, $\frac{\partial \hat{t}}{\partial r_0} = \frac{d(J+1)}{J} > 0$,

and $\frac{\partial \hat{t}}{\partial J} = \frac{(h_0+c_1-h_1-\bar{c})-d(1+r_0-r_1)}{J^2} > 0$;

(ii) $\frac{\partial \hat{t}}{\partial r_1} = \frac{-d(J+1)}{J} < 0$, $\frac{\partial \hat{t}}{\partial h_0} = \frac{-1}{J} < 0$, and $\frac{\partial \hat{t}}{\partial c_1} = \frac{-1}{J} < 0$; and

(iii) $\frac{\partial \hat{t}}{\partial c_0} = 0$.

Corollary 1 demonstrates how parameters in the model affect the regulator's equilibrium taxes or subsidies. The regulator will raise taxes or lower subsidies to encourage the adoption of stray dogs/cats when the happiness of raising strays (h_1), the cost of breeding pets ($\bar{c}$), the marginal environmental damage caused by strays (d), the probability of abandoning purchased dogs/cats (r_0), or the number of pet shops (J) increases. That is what Corollary 1(i) shows. By contrast, the regulator will lower taxes or raise subsidies to encourage the purchases of pet animals if the probability of abandoning adopted dogs/cats (r_1), the happiness of raising purchased pets (h_0), or the cost of raising adopted strays (c_1) increases. This is the content of Corollary 1(ii).

However, the optimal subsidies or taxes are not affected by c_0. Changing c_0 will influence the social welfare directly by varying term $-[(c_0+c_1)(\hat{x})^2]/2$ in the consumer surplus in (6), and indirectly through varying pet-animal demand $\hat{x}$ in (10). Based on the first-order condition, we find that the direct and the indirect effects will cancel out with each other.[5] Thus, c_0 does not affect $\hat{t}$.

We would like to mention two interesting implications. First, the result of $\partial \hat{t}/\partial J = [(h_0+c_1-h_1-\bar{c})-d(1+r_0-r_1)]/J^2 > 0$ implies that when the pet-animal market becomes less competitive (i.e., smaller J), the regulator is more likely to subsidize pet shops, because the

5 Using $\hat{x}$ in the first-order condition of $\hat{t}$ yields $\partial SW/\partial t = h_0 - h_1 + c_1 - (c_0+c_1)\hat{x} - \bar{c} - d(1+r_0-r_1) = h_0 - h_1 + c_1 - (c_0+c_1)\,[J(h_0-h_1+c_1-\hat{t}-\bar{c})]/[(c_0+c_1)(J+1)] - \bar{c} - d(1+r_0-r_1) = h_0 - h_1 + c_1 - \bar{c} - [J(h_0-h_1+c_1-\hat{t}-\bar{c})]/(J+1) - d(1+r_0-r_1) = 0$, which is independent of c_0.

equilibrium pet-animal amount as well as social welfare will decrease. Thus, the regulator is apt to subsidize pet shops to raise the trading amounts of pet animals. The same result will hold even when pet shops' cost functions change from linear to quadratic ones as shown in Corollary 4(ii). Second, the results under a monopoly pet-animal market can be obtained by letting $J = 1$ in this section. It is easy to see that the comparative static results under a monopoly pet-animal market will be the same as those under an oligopoly pet-animal market.

3.2. A Perfectly Competitive Pet-Animal Market

The well-known Cournot limit theorem states that the perfect competition is the limit of a Cournot competition with firms producing homogeneous products using identical constant marginal costs, when the number of firms approaches infinity. Thus, we can obtain our results in a perfectly competitive pet-animal market by letting J in Subsection 3.1 approach infinity as follows.

Proposition 2.

Suppose the condition in (14) holds. Then the SPNE, $(t^*,\ x^*,\ p^*)$, *in a perfectly competitive pet animal market is*

$$t^* = d(1 + r_0 - r_1) > 0,$$
$$x^* = \frac{1}{(c_0 + c_1)}[(h_0 + c_1 - h_1 - \bar{c}) - d(1 + r_0 - r_1)] = \hat{x} > 0, \text{ and}$$
$$p^* = \bar{c} > 0.$$

Proof. We can acquire $(t^*,\ x^*,\ p^*)$ by letting $J \to \infty$ for $(\hat{t},\ \hat{x},\ \hat{p})$ in Proposition 1.

Different from Proposition 1, the regulator will always tax pet buyers here. The intuition is simple. Since the number of pet shops is close to infinity in a perfectly competitive pet-animal market, it is optimal for the regulator to tax the purchases of dogs/cats as implied by Proposition 1. Then, the equilibrium amount of pet animals will be reduced, and the environmental damage caused by abandoned purchased pets due to the large number of pet shops becomes lower. Moreover, other factors affecting the equilibrium taxes include d, r_0, and r_1. These parameters' functions are summarized below.

Corollary 2.

Suppose the condition in (14) holds. Under a perfectly competitive pet-animal market with linear costs, we have $\partial t^*/\partial d = (1 + r_0 - r_1) > 0$, $\partial t^*/\partial r_0 = d > 0$, *and* $\partial t^*/\partial r_1 = -d < 0$.

The intuition behind Corollary 2 is similar to that behind Corollary 1.

Finally, we would like to demonstrate that equilibrium pet amount x^* under a perfectly competitive pet-animal market also maximizes the social welfare. Denote x_s the amount of pet animals, which maximizes the social welfare. That is, x_s solves the problem of

$$\max_x \; SW = h_1 - \frac{c_1}{2} + x(h_0 + c_1 - h_1 - \bar{c}) - \frac{(x)^2}{2}(c_0 + c_1)$$
$$-d[\bar{Q} - 1 + r_1 + x(1 + r_0 - r_1)].$$

The associated first-order and second-order derivatives are

$$\frac{\partial SW}{\partial x} = h_0 + c_1 - h_1 - \bar{c} - x(c_0 + c_1) - d(1 + r_0 - r_1) \text{ and} \tag{15}$$

$$\frac{\partial^2 SW}{\partial x^2} = -(c_0 + c_1) < 0. \tag{16}$$

Under the condition in (14), the derivatives in (15) and (16) suggest the existence of an interior solution,

$$x_s = \frac{h_0 + c_1 - h_1 - \bar{c} - d(1 + r_0 - r_1)}{(c_0 + c_1)}, \tag{17}$$

with $0 < x_s < 1$.[6] Moreover, we have $x_s = x^* = \hat{x}$. These imply that

[6] Similar arguments used in footnote 4 can be employed to show $0 < x_s < 1$.

the optimal taxes or subsidies set in imperfectly and perfectly competitive pet-animal markets can correct the market failure caused by strays' externalities so that the equilibrium pet-animal amounts in both markets will be the first-best solutions as well. However, we would like to point out that this result is derived under the assumptions of all pet shops having an identical cost function and producing homogeneous products, the regulator considering no deadweight loss caused by taxes, no tax revenue being taken away, as well as no tax-evasion behavior of pet shops occurring.

Moreover, properties of x_s in (17) are summarized below.

Corollary 3.

Suppose the condition in (14) holds. Under a competitive pet-animal market with linear costs, we have

(i) $\frac{\partial x_s}{\partial h_1} = \frac{-1}{c_0+c_1} < 0$, $\frac{\partial x_s}{\partial \bar{c}} = \frac{-1}{c_0+c_1} < 0$, $\frac{\partial x_s}{\partial d} = \frac{-(1+r_0-r_1)}{c_0+c_1} < 0$,

$\frac{\partial x_s}{\partial r_0} = \frac{-d}{c_0+c_1} < 0$,

$\frac{\partial x_s}{\partial c_0} = \frac{-[h_0+c_1-h_1-\bar{c}-d(1+r_0-r_1)]}{(c_0+c_1)^2} < 0$; and

(ii) $\frac{\partial x_s}{\partial r_1} = \frac{d}{c_0+c_1} > 0$, $\frac{\partial x_s}{\partial h_0} = \frac{1}{c_0+c_1} > 0$, and

$\frac{\partial x_s}{\partial c_1} = \frac{c_0-h_0+h_1+\bar{c}+d(1+r_0-r_1)}{(c_0+c_1)^2} > 0$.

Corollary 3 demonstrates how parameters in the model affect the social optimal amount of pet animals. When the happiness of raising stray dogs/cats (h_1), the cost of breeding pets ($\bar{c}$), the marginal environmental damage caused by strays (d), or the probability of abandoning purchased dogs/cats (r_0) increases, the socially optimal amount of pet animals will decrease because the regulator will raise taxes or lower subsidies as in Corollary 1(i) to reduce pets' trading. That is what Corollary 3(i) states. It is worthy to mention that higher c_0 will lower x_s as well even though c_0 does not affect the optimal taxes or subsidies as shown by Corollary 1(iii), because higher costs of raising purchased dogs/cats will indirectly lower the incentive of buying pets and thus lower pets' trading. By contrast, when the probability of abandoning adopted dogs/cats (r_1), the happiness of raising purchased pets (h_0), or the cost of raising adopted strays (c_1) increases, the socially optimal amount of pet animals will increase too. That is because higher values of these parameters will make the regulator lower its taxes or increase its subsidies to promote pets' trading. This is the content of Corollary 3(ii).

4. Extensions

In this section, we extend our frameworks in two directions. First, instead of maximizing social welfare, the regulator is assumed to minimize the number of stray animals or the environmental damage caused by them. Second, instead of linear functions, a quadratic cost function of pet animal shops or a quadratic environmental-damage function is considered. After analyzing these extensions, we can infer the robustness of our results in Propositions 1 and 2.

4.1. Minimizing the Number of Stray Animals

Suppose that the regulator wants to minimize the number of stray dogs/cats. The game structure here is the same as that in Section 3 except that the regulator now chooses t_m to solve the problem of

$$\begin{aligned} &\min_{t} \ \bar{Q} - (1-\hat{x}) + r_0\hat{x} + r_1(1-\hat{x}) \\ &\text{s.t.} \ -\underline{t} \le t \le \bar{t} \end{aligned} \tag{18}$$

under an imperfectly competitive pet-animal market. As in Subsection 3.1, the regulator is allowed to subsidize or tax the purchases of dogs/cats. Thus, t_m can be negative or positive. To assure the existence of the solutions, we impose an upper bound for tax ($\bar{t}$) and for subsidy ($-\underline{t}$). On the other hand, if the regulator aims to minimize the environmental damage caused by strays, it will choose an optimal tax or subsidy to solve the problem of

$$\begin{aligned} &\min_{t} \ d[\bar{Q} - (1-\hat{x}) + r_0\hat{x} + r_1(1-\hat{x})] \\ &\text{s.t.} \ -\underline{t} \le t \le \bar{t}. \end{aligned} \tag{19}$$

It is easy to see that the solutions of problem (19) are the same as those of problem (18), and the results are as follows.

Proposition 3.

Suppose that the condition in (14) holds and the regulator aims to minimize the number of stray animals or the environmental damage caused by them. Then it is optimal for the regulator to set the tax as high as possible no matter the pet-animal market structure is perfectly or imperfectly competitive.

Proof. See the Appendix.

It is worthy to mention that the results of Proposition 3 will remain true even though the breeding-cost functions and/or strays' environmental-damage functions become quadratic, because the key elements of Proposition 3 are $\partial x^*/\partial t < 0$ and $\partial \hat{x}/\partial t < 0$, which still hold under quadratic breeding-cost and/or environmental-damage functions.

4.2. Pet-Animal Shops Having Quadratic Cost Functions

In this section, we assume that pet-animal shops have quadratic, rather than linear, breeding costs. Similar results can be obtained if we replace strays' linear environmental-damage functions by quadratic ones.[7] Here we present the results for pet-animal shops having quadratic breeding costs only. Suppose that the cost function of pet shop j is $c(q^j) = (\bar{c}/2)(q^j)^2$ under an imperfectly competitive pet-animal market for all j. By applying the same method used in Subsection 3.1, we can obtain all pet shops providing the same pet-animal amount $\check{q} = (h_0 + c_1 - h_1 - t)/[(c_0 + c_1)(J + 1) + \bar{c}]$ given regulator's tax or subsidy t, which leads to equilibrium amount $\check{x} = J\check{q} = [J(h_0 + c_1 - h_1 - t)]/ [(c_0 + c_1)(J + 1) + \bar{c}]$ and equilibrium price $\check{p} = [(c_0 + c_1 + \underline{a}rc)(h_0 + c_1 - h_1 - t)]/[(c_0 + c_1)(J + 1) + \bar{c}]$ in the pet-animal market. Then, at $(\check{x}, \check{p})$, the regulator's social welfare function becomes

$$SW = h_1 - \frac{c_1}{2} + \check{x}(h_0 + c_1 - h_1) - \frac{(\check{x})^2}{2}\left(c_0 + c_1 + \frac{\bar{c}}{J}\right)$$
$$-d[\bar{Q} - 1 + r_1 + \check{x}(1 + r_0 - r_1)].$$

The associated first-order and second-order conditions for optimal $\check{t}$ are

$$\frac{\partial SW}{\partial t} = \frac{-J[h_0 + c_1 - h_1 - d(1 + r_0 - r_1) - (c_0 + c_1 + \frac{\bar{c}}{J})\check{x}]}{[(c_0 + c_1)(J + 1) + \bar{c}]} = 0, \quad (20)$$

and

$$\frac{\partial^2 SW}{\partial t^2} = \frac{-(c_0 + c_1 + \frac{\bar{c}}{J})J^2}{[(c_0 + c_1)(J + 1) + \bar{c}]^2} < 0.$$

Solutions of (20) are

$$\check{t} = d(1 + r_0 - r_1) - \frac{(c_0 + c_1)[h_0 + c_1 - h_1 - d(1 + r_0 - r_1)]}{J(c_0 + c_1) + \bar{c}} \geq (\leq) 0$$

$$\text{iff } d(1 + r_0 - r_1)[(J + 1)(c_0 + c_1) + \bar{c}] \geq (\leq)\ (c_0 + c_1)[h_0 + c_1 - h_1], \text{ and} \quad (21)$$

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[7] Under a quadratic environmental-damage function, the regulator still subsidizes or taxes dogs/cats buyers in an imperfectly competitive pet-animal market, and still tax dogs/cats buyers in a perfectly competitive pet-animal market. However, the impacts of some model's parameters on the optimal taxes or subsidies are uncertain. These results are available upon request.

$$\check{p} = \frac{(c_0 + c_1 + \bar{c})[h_0 + c_1 - h_1 - d(1 + r_0 - r_1)]}{J(c_0 + c_1) + \bar{c}}. \tag{22}$$

At $(\check{t},\ \check{p})$, condition (3) is reduced to

$$h_1 - c_1 + d(1 + r_0 - r_1) < h_0 < h_1 + c_0 + \frac{\bar{c}}{J} + d(1 + r_0 - r_1). \tag{23}$$

As in the imperfectly competitive pet-animal market with linear breeding costs, inequality in (21) implies that the regulator will subsidize or tax dogs/cats buyers even when the breeding-cost function becomes nonlinear. Moreover, under condition (23), the comparative statics results of $\check{t}$ are as follows.

Corollary 4.

Suppose that the condition in (23) holds. Under an imperfectly competitive pet-animal market with quadratic breeding costs, we have

(i) $\frac{\partial \check{t}}{\partial r_0} = \frac{d[(c_0+c_1)(J+1)+\bar{c}]}{J(c_0+c_1)+\bar{c}} > 0$ and $\frac{\partial \check{t}}{\partial r_1} = \frac{-d[(c_0+c_1)(J+1)+\bar{c}]}{J(c_0+c_1)+\bar{c}} < 0$;

(ii) $\frac{\partial \check{t}}{\partial d} = \frac{(1+r_0-r_1)[(c_0+c_1)(J+1)+\bar{c}]}{J(c_0+c_1)+\bar{c}} > 0$ and
$\frac{\partial \check{t}}{\partial J} = \frac{(c_0+c_1)^2[h_0+c_1-h_1-d(1+r_0-r_1)]}{[J(c_0+c_1)+\bar{c}]^2} > 0$;

(iii) $\frac{\partial \check{t}}{\partial h_0} = \frac{-(c_0+c_1)}{[J(c_0+c_1)+\bar{c}]} < 0$ *and* $\frac{\partial \check{t}}{\partial h_1} = \frac{(c_0+c_1)}{[J(c_0+c_1)+\bar{c}]} > 0$;

(iv) $\frac{\partial \check{t}}{\partial c_0} = \frac{-\bar{c}[h_0+c_1-h_1-d(1+r_0-r_1)]}{[J(c_0+c_1)+\bar{c}]^2} < 0$ and
$\frac{\partial \check{t}}{\partial c_1} = \frac{-\bar{c}[h_0+c_1-h_1-d(1+r_0-r_1)]}{[J(c_0+c_1)+\bar{c}]^2} < 0$; and

(v) $\frac{\partial \check{t}}{\partial \bar{c}} = \frac{(c_0+c_1)[h_0+c_1-h_1-d(1+r_0-r_1)]}{[J(c_0+c_1)+\bar{c}]^2} > 0.$

Proof. The proofs are pretty straightforward and thus omitted.

Corollary 4 shows that the impacts of all parameters on the equilibrium taxes or subsidies are the same qualitatively as those in Corollary 1 except that of c_0 on $\check{t}$. Under linear breeding costs, Corollary 1(iii) shows that the direct and indirect effects of changing c_0 on $\hat{t}$ cancel out with each other. However, this will not occur if the breeding-cost functions are quadratic. Moreover, the indirect effect of changing c_0 on $\check{t}$ will outweigh its direct effect.[8] As shown in footnote 5 under linear breeding costs, we have $\hat{x} = [J(h_0 + c_1 - h_1 - t - \bar{c})]/[(c_0 + c_1)(J + 1)]$ so that the term $(c_0 + c_1)\hat{x}$ in the social welfare function is independent of c_0. However, under quadratic breeding costs, we have $\check{x} = [J(h_0 + c_1 - h_1 - t)]/[(c_0 + c_1)(J + 1) + \bar{c}]$. Then, the term $(c_0 + c_1)\check{x}$ in the social welfare function depends on c_0, and so does $\partial SW/\partial t$. That is because higher c_0 will lead to a larger decrease of equilibrium pet-animal amount under quadratic than under linear breeding costs. To avoid the fall of social welfare, it is better for the regulator to lower taxes or raise subsidies as shown by Corollary 4(iv).

Finally, by letting J approach infinity for $(\check{t}, \check{p})$ in (21) and (22), we can obtain the equilibrium tax or subsidy, the equilibrium price, the equilibrium pet-animal amount for an individual pet shop, and the equilibrium pet-animal amount for all pet shops, $(\tilde{t}, \tilde{p}, \tilde{q}, \tilde{x})$, in a perfectly competitive pet-animal market with quadratic breeding costs, where

$$\tilde{t} = d(1 + r_0 - r_1) > 0,\ \tilde{p} = 0,\ \tilde{q} = \lim_{J\to\infty} \check{q} = 0,\ \text{and}$$

$$\tilde{x} = \frac{[h_0 + c_1 - h_1 - d(1 + r_0 - r_1)]}{(c_0 + c_1)} > 0. \tag{24}$$

At $(\tilde{t}, \tilde{p})$, condition (3) is reduced to

$$h_1 - c_1 + d(1 + r_0 - r_1) < h_0 < h_1 + c_0 + d(1 + r_0 - r_1). \tag{25}$$

As under linear breeding costs, it is optimal for the regulator to tax dogs/cats buyers when breeding-cost functions become quadratic in a perfectly competitive pet-animal market. It is worthy to discuss the equilibrium variables listed in (24). First, equilibrium tax $\tilde{t}$ in (24) is

[8] Here we apply Frank's (1965) Cournot limit theorem under a general set-up of demand and cost functions.

the same as t^* in a perfectly competitive pet-animal market with linear breeding costs. Since the number of pet-animal shops approaches infinity in a perfectly competitive pet-animal market, individual shops are negligible. Thus, the equilibrium taxes will be the same whether breeding costs are linear or quadratic. This then implies that the comparative-static results of $\tilde{t}$ under condition (25) are the same as those of t^*, and hence omitted here. Second, in a perfectly competitive pet-animal market, the supply function of each pet shop is its marginal cost function, $\bar{c}q^j$, which has a minimum efficient scale at $q^j = 0$ for all j. Thus, the equilibrium price of the pet-animal market will be zero and all shops in the market will produce a pet-animal amount arbitrarily close to zero. However, since there are infinite pet shops, the total pet-animal amount supplied at the equilibrium will be non-zero. That is why we have $\tilde{p} = 0$, $\tilde{q} = 0$, and $\tilde{x} > 0$ as shown in (24).

5. Conclusions

Being nice to animals, especially dogs/cats, is not only humane, but also has huge economic values. Many problems and costs existing in our living environments can be resolved if we are able to control stray animals. This paper thus tries to seek economic-policy solutions based on different goals pursued by the regulator. Our models have two features. First, we use game theoretical setups to characterize the interactions among the regulator, pet shops, and consumers. Second, we endogenize the purchasing and adopting behaviors of pet-animal consumers. We find that the equilibria will be affected by regulator's goals. When the regulator aims to maximize the social welfare, the pet-animal market structures will affect the results. If the market is imperfectly competitive, the regulator may tax or subsidize pet-animal buyers, while the regulator will tax pet-animal buyers if the market is perfectly competitive. These results hold whether breeding-cost and strays' environmental-damage functions are linear or quadratic. By contrast, when the regulator aims to minimize the number of stray animals, which is equivalent to minimizing the environmental damage caused by strays, the regulator should always tax dog/cat buyers whatever the pet animal market structure is, and whether function forms of breeding costs and strays' environmental damage are linear or quadratic.

We also investigate how parameters in the models affect equilibrium taxes or subsidies. In an imperfectly competitive pet-animal market, we find that the regulator will raise taxes or lower subsidies when the probability of abandoning purchased dogs/cats increases, the probability of abandoning adopted dogs/cats falls, the environmental damage caused by strays expands, the happiness from raising the purchased dogs/cats decreases, the happiness from raising stray dogs/cats rises, the cost of raising stray animals decreases, the breeding cost of dogs/cats rises, or the number of pet shops increases. The first three comparative-static results remain true in a perfectly competitive pet-animal market. All the results described above hold under both linear and quadratic breeding-cost functions.

Finally, our work can be extended in the following directions. First, instead of taxing or subsidizing pet-animal buyers, economic-policy instruments can also be employed to deal with other pet consumers. For instance, subsidizing adopters of stray animals under the same setups of this research is worth exploring. Then, through comparisons, we will know which policy is more effective in solving stray-animal problems under different goals pursued by the regulator. Second, it will be interesting and meaningful to consider rational animal shelters. For instance, they may want to minimize their running costs. This could have uncertain impacts on equilibrium taxes or subsidies of the regulator. To lower running costs, the shelters will make fewer efforts to take care of stray animals or even increase using the catch-and-kill program. Thus, the environmental damage will rise due to more strays and the social welfare will decrease. But decreasing shelters' running costs will raise the social welfare. Therefore, the net effect is uncertain, and the equilibrium taxes or subsidies may increase or decrease. These issues deserve further investigations.

Appendix

Proof of Proposition 3:

Define Lagrangian function $L = \bar{Q} - (1 - \hat{x}) + r_0\hat{x} + r_1(1 - \hat{x}) - \lambda_1[t + \underline{t}] + \lambda_2[t - \bar{t}]$. The associated first-order conditions are

$$\frac{\partial L}{\partial t} = (1 + r_0 - r_1)\frac{\partial \hat{x}}{\partial t} - \lambda_1 + \lambda_2 \geq 0,\ t \cdot \frac{\partial L}{\partial t} = 0, \tag{A1}$$

$$\frac{\partial L}{\partial \lambda_1} = (-t - \underline{t}) \leq 0,\ \lambda_1 \cdot \frac{\partial L}{\partial \lambda_1} = 0,\ \text{and} \tag{A2}$$

$$\frac{\partial L}{\partial \lambda_2} = (t - \bar{t}) \leq 0,\ \lambda_2 \cdot \frac{\partial L}{\partial \lambda_2} = 0. \tag{A3}$$

Equation (10) implies $\partial\hat{x}/\partial t = -J/[(c_0 + c_1)(J + 1)] < 0$. There are three possible solutions. First, if $\tilde{t} \in (-\underline{t},\ \bar{t})$, we have $\lambda_1 = \lambda_2 = 0$. Then, $\partial L/\partial t = -[(1+r_0-r_1)J]/[(c_0+c_1)(J+1)] < 0$, which contradicts the condition in (A1). Second, if $\tilde{t} = -\underline{t}$, then we have $\lambda_1 \geq 0$ and $\lambda_2 = 0$ by (A2)-(A3). Accordingly, $\partial L/\partial t = -[(1 + r_0 - r_1)J]/[(c_0 + c_1)(J + 1)] - \lambda_1 < 0$, which contradicts the condition in (A1) again. Third, if $\tilde{t} = \bar{t}$, then we have $\lambda_1 = 0$ and $\lambda_2 \geq 0$ by (A1)-(A2). Consequently, $\partial L/\partial t = -[(1 + r_0 - r_1)J]/[(c_0 + c_1)(J + 1)] + \lambda_2$. Letting $\lambda_2 = (1 + r_0 - r_1)/(c_0 + c_1 + \beta) > 0$, we obtain a unique solution, i.e., $det = \bar{t}$. It suggests that the regulator will tax pet shops, and set the tax rate as high as possible. Similar arguments can be applied to the perfectly competitive pet-animal market because $\partial x^*/\partial t = \lim_{J\to\infty} \partial\hat{x}/\partial t = 1/(c_0 + c_1) < 0$.

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解決流浪動物問題的經濟政策

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摘　要

本文嘗試探討處理流浪動物的最適經濟政策。我們建構了一個兩階段的賽局，用以刻劃主管機關、寵物店和消費者之間的互動。尤其，一個簡單的 Hotelling 模型可用來將購買與領養寵物者的行為內生化。我們的結果顯示，當社會福利的極大化是目標且寵物市場為不完全競爭時，主管機關可以對寵物的購買者課稅或進行補貼。另一方面，當寵物市場為完全競爭時，主管機關應該對購買寵物者課稅。相對地，當流浪動物數目的極小化是目標時，對寵物的購買者課稅是主管機關的最佳選擇。無論寵物的飼養成本和流浪動物造成的環境代價是線性的或二次式的函數型態，也無論寵物市場為完全或不完全競爭，這個結果都成立。

關鍵詞：流浪動物、外部性、稅、補貼、完全競爭、不完全競爭
JEL 分類代號：Q57, Q58

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