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PIGS AND GUINEA PIGS: A NOTE ON THE ETHICS OF ANIMAL EXPLOITATION*

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Animal exploitation in research or in food production has two important consequences: the first is that the animals may suffer pain, discomfort, illness and isolation, and may live short lives; the second is that these activities cause large numbers of animals to be brought into existence.

Much of the writing and thinking about the morality of these activities focuses on the first of these facts. Scientists who use animals in experiments, philosophers, and vegetarians ask whether the animal suffering can be justified by appeal to the gains to humans – better health, longer lives, tastier food, safer cosmetics – that result.

But there is another dimension to the discussion. If we reduce our consumption of meat, there will be fewer cattle in the world; if we adopt less animal-intensive methods of research, there will be fewer guinea pigs.[1] This essay attempts to unit both of these phenomena in a single exercise in applied ethics. We combine an explicit ethical view that accords all sentient creatures moral standing with simple models of animal food production and animal research.

The ethics we use are a generalisation of utilitarianism called critical-level utilitarianism (Blackorby and Donaldson, 1984). It collapses to ordinary utilitarianism when populations are constant, but is a family of ethical rules for populations that vary, and one member of the family is classical utilitarianism. Non-human and human levels of well-being are given equal weight, in accordance with Singer's (1975, 1979, 1980) elegant arguments, but the qualitative results require only that animals receive some weight. In addition, the results are consistent with concern about inequality in the distribution of

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[1] There are approximately one billion cattle in the world, one for every five people (F. Kraus, Quirks and Quarks, CBC Radio, Jan. 20, 1990). Cattle contribute a significant amount of methane (a greenhouse gas) to the atmosphere. Rowan (1984) estimates that, in 1980, approximately 70 million laboratory animals were used in the United States. This estimate is consistent with an estimate of 110 million for world use. Some wild animals are used in research but most laboratory animals are bred for the purpose.

well-being. Because information about the well-being of all concerned individuals is sufficient to make moral judgements, ethical theories of this type are often called 'welfarist'. Critical-level utilitarianism, and its extension to many species are discussed in sections I and II.

Section III contains a simple model of animal-using research. Because research is difficult to quantify, we hold its level constant. In addition, humans have identical utility functions and consumption bundles, and guinea pigs, the experimental subjects, have identical utility functions, consumption, and laboratory experience. As a benchmark case we describe an equilibrium in which investigators minimise the cost of conducting research. We then contrast this with two different ethically optimal arrangements: the 'first-best', in which both the number and standard of living of laboratory animals is optimally set, and the 'second-best', in which only the number is adjusted.

A simple economic model of animal farming is presented in section IV. There is a fixed population of people, and a single species of animals (pigs) is raised for food. Animal well-being depends on the resources (grain) devoted to them, and human well-being depends on both grain and pork consumed. As in section III, members of the same species have the same utility functions, consumption, and, in the case of pigs, the same farm experience and length of life. Competitive market equilibrium is described, and contrasted with first-best and second-best ethical optima.

The questions we ask are:

- Is eating animals and/or using them in research morally acceptable?
- Should our diets rely less on animal products?
- Is unregulated research too animal intensive?
- Is the unregulated level of well-being of farm and research animals too low?
- What policies can contribute to ethical improvement?

Section V contains a discussion of alternative approaches to the ethical treatment of animals. We focus on the adequacy of the alternatives in dealing with the population issue.

Section VI contains a discussion of policy (necessarily brief in a theoretical essay), an examination of limitations of the models, and partial answers to the questions (above). An appendix contains proofs of several theorems.

Although we believe that there are ethical lessons to be learned from this paper, we also believe that it provides a consistent framework for the consideration of difficult moral problems involving animals. There is, after all, a case for using animals in research even when they are granted moral standing. This paper contains a particular formulation of the problem that allows such a case to be made. In order to decide whether a particular experiment is morally acceptable or not, additional information – on benefits to humans and animal suffering – is needed.

I. SOCIAL EVALUATION AND POPULATION SIZE: THE CASE OF A SINGLE SPECIES

Suppose that $X = \{x, y, \ldots\}$ is a set of feasible social states. Each state is a complete description of the history of the planet, from distant past to far future. Each element of X is feasible: all have a common past.

Different social states may have different populations and population sizes. For a single species, we (1984) have proposed several welfarist criteria (the well-being of individuals who are alive in different states is sufficient for evaluation). When social evaluations rank states that have the same number of individuals, the comparisons are utilitarian.[2] When the evaluations involve different numbers of individuals, we suggest that social states be ranked with the value function

$$V_\alpha(x) = \sum_{k \in N(x)} [U^k(x) - \alpha], \tag{1}$$

where $U^k(x)$ is the lifetime utility (an index of lifetime well-being) of person k in state x with the convention that a utility of zero is a life of hedonic neutrality, $N(x)$ is the set of people alive in x, and α is a lifetime utility level (normally positive). α is a parameter that can be varied, and each choice of α results in a (possibly) different ordering of X.

$V_\alpha(x)$ is the sum of the excess of individual utilities above the critical level α (negative if below α); states with higher values of $V_\alpha(\cdot)$ are preferred to states with lower values (with social indifference for equality). We call this rule critical-level utilitarianism. When α is zero, the rule becomes classical utilitarianism. Positive values of α make the ordering of states different from the classical utilitarian one. Several comments on critical-level utilitarianism are in order, as follows.

For same-individual or same-number choices, α disappears from (1), and the ranking is utilitarian.

Equation (1) satisfies the 'critical-level population principle' with the critical utility level equal to α. Suppose that state y has exactly one more individual – person l say – than state x, and that each individual alive in x is alive in y. Suppose further, that the well-being of every member of the population that is common to x and y is the same, individual by individual: $U^k(x) = U^k(y)$ for all $k \in N(x)$. Then the critical-level population principle declares x socially indifferent to y if the added individual's utility in y is exactly the critical level: $U^l(y) = \alpha$. It can be shown that (1) is the only rule ordering X satisfying same-individual utilitarianism and the critical-level population principle with the critical utility level equal to α.[3]

[2] Parfit (1982) distinguishes three kinds of policy options for human populations. They are 'same-people' choices, 'same-number' choices, and 'different-number' choices. Welfarism eliminates the distinction between same-number and same-people choices.

[3] The theorem needs a domain axiom that allows all possible populations to appear in X, and allows all possible utility vectors. Given that, for any $x, y \in X$, construct w, z with $N(w) = N(z) = N(x) \cup N(y)$, $U^i(w) = U^i(x)$ for all $i \in N(x)$, $U^i(w) = \alpha$ for all $i \in N(w) \setminus N(x)$, $U^i(z) = U^i(y)$ for all $i \in N(y)$, $U^i(z) = \alpha$ for all $i \in N(z) \setminus N(y)$. Then, by the critical-level population principle (α), z is socially indifferent to y and w to

Critical-level utilitarianism places a floor, α, on the trade-off between average utility (standard of living) and numbers. This can be seen easily by rewriting (1) as

$$V_\alpha(x) = |N(x)|\,[\bar{U}(x) - \alpha], \tag{2}$$

where $|N(x)|$ is the number of people alive in x (at any time), and $\bar{U}(x) := \sum_{k\in N(x)} U^k(x)/|N(x)|$ is average utility in x. When the critical level is zero (classical utilitarianism), any reduction in a positive average utility can be 'made up for' by an increase in numbers as long as the reduced average utility is positive.[4] For a positive critical level, this can occur only when both average utilities exceed the critical level. Below α, this is not possible; with average utility below α, a larger population with the same average is socially dispreferred. Above the critical level, higher values of α 'sharpen' the trade-off between average utility and numbers: more individuals are needed to compensate for a given reduction in average utility.

Critical-level utilitarianism is fully welfarist and has no counter-intuitive results on killing. If an individual's utility is below α, death does not raise $V_\alpha(\cdot)$ because that individual is alive in every feasible state. For example, using critical-level utilitarianism with $\alpha = 3$, a population of one with a utility equal to 4 is preferred to a population of two with utilities of 4 and 2. But if, in the second state, the low-utility person is killed, that lowers his or her lifetime utility without changing the number of people alive; this reduces $V_\alpha(\;)$ and is therefore socially dispreferred (see Blackorby and Donaldson (1991) for a discussion). Other things equal, however, the birth of an individual with lifetime utility below the critical level should be prevented ($V_\alpha(\cdot)$ falls); thus, critical-level utilitarianism distinguishes between killing and not being born. In addition, critical-level utilitarianism gives value to the length of individual lives: a state in which two people live thirty years each at a given utility level in each year is socially inferior to one in which one individual lives for sixty years at the same level (see Broome (1991)).

Individual utilities may fall below the positive critical level α for two quite different reasons. The first is that utility per period lived (the standard of living) may be low or negative, and the second is that the individual's lifetime may be abnormally short. The second effect is important for non-human animal populations used by humans.

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x, so that x is weakly preferred to y if and only if w is weakly preferred to z. But, by same-individual utilitarianism, this occurs if and only if

$$\begin{aligned}
&\sum_{i\in N(w)} U^i(w) \geqslant \sum_{i\in N(z)} U^i(z)\\
&\leftrightarrow \sum_{i\in N(x)} U^i(x) + \sum_{i\in N(w)\setminus N(x)} \alpha \geqslant \sum_{i\in N(y)} U^i(y) + \sum_{i\in N(z)\setminus N(y)} \alpha\\
&\leftrightarrow \sum_{i\in N(x)} [U^i(x)-\alpha] + \sum_{i\in N(y)\cup N(x)} \alpha \geqslant \sum_{i\in N(y)} [U^i(y)-\alpha] + \sum_{i\in N(x)\cup N(y)} \alpha\\
&\leftrightarrow \sum_{i\in N(x)} [U^i(x)-\alpha] \geqslant \sum_{i\in N(y)} [U^i(y)-\alpha]\\
&\leftrightarrow V_\alpha(x) \geqslant V_\alpha(y).
\end{aligned}$$

4 Parfit (1982) calls the trade-off possibilities in classical utilitarianism the 'repugnant conclusion'.

When population is chosen optimally, an increase in α will never increase optimal population size and usually decreases it. The increased critical level reduces the ability of numbers to make up for losses in average utility at all levels, and hence decreases the optimal population.[5]

Critical-level utilitarianism allows increases in utility to some individuals to be traded off against losses to others without regard to utility inequality. The value function (1) of critical-level utilitarianism can be modified to reflect a concern for inequality. Specifically, if h is a concave function then the value function

$$V_{\alpha}^{h}(x) = \sum_{k \in N(x)} \{h[U^{k}(x)] - h(\alpha)\} \tag{3}$$

gives a greater weight to changes in low utilities than to changes in high ones. The critical-level population principle is satisfied by V_{α}^{h} with α as the critical level of utility. Any degree of inequality aversion that allows a trade-off between total utility (for a fixed population) and inequality is permitted. Indeed, by suitable choice of the function h, the rule in (3) can be brought arbitrarily close to maximin utility.[6] Equation (3) is not, however, mathematically different from (1). This is because (3) is (1) for the utility functions $h[U^{k}(\cdot)]$ and the critical level $h(\alpha)$. Hence, in what follows, we confine our attention to (1). Of course, while our qualitative theorems are unchanged by (3), actual optimal levels are different. (See Blackorby and Donaldson (1984) for a discussion.)

The behaviour of (1) has been tested by us (1984) in the simplest possible population problem that we call the 'pure population problem'. A fixed amount of a single resource is to be given to a number of individuals (all of a single species with identical utility functions).[7] Population size and the distribution of 'income' are to be chosen. Equations (1) and (3) require equality of consumption, and the optimal population decreases as α increases. There is a level of α such that the optimal population is *one*, the number that the maximisation of average utility demands. Lower, positive levels of α result in population levels between one and the classical utilitarian optimum.

II. SOCIAL EVALUATION AND POPULATION SIZE: SEVERAL SPECIES

The value function (1) (or (3)) can be generalised to take account of two or more populations of different species.[8] The augmented function, for two species, humans and pigs (for food) or guinea pigs (for research) is

$$V_{\alpha}(x) = \sum_{i \in N^{H}(x)} [U^{i}(x) - \alpha_{H}] + \sum_{j \in N^{P}(x)} [U^{j}(x) - \alpha_{P}] \tag{4}$$

[5] See Lemma 1 in the appendix and/or Blackorby and Donaldson (1984).

[6] Maximin utility, for a fixed population, uses as value function the minimum utility in a state. If $h(t) = t^{r}/r$, $r < 1$, $r \neq 0$ (say), and all utilities are positive, the ordering of states by V_{α}^{h} approaches the ordering produced by maximin utility when r approaches minus infinity.

[7] In that model, a utility level of zero is achieved with a positive subsistence level of consumption, and the utility function is strictly concave above subsistence.

[8] We restrict our attention to two species; the generalisation to more than two is obvious.

where $\alpha = (\alpha_H, \alpha_P)$. In (4), $N^H(x)$ is the set of humans alive in x and $N^P(x)$ is the set of pigs or guinea pigs alive in x. $U^k(x)$ is the lifetime utility or well-being of a human or pig depending on whether k is in $N^H(x)$ or $N^P(x)$. We take the view that, for a fixed population of humans and pigs, utilities should be given equal weight without attention to species.[9] This satisfies the principle of 'equal consideration of interests' (Singer, 1975, 1979, 1980). If, however, pigs are given a lower (positive) weight our qualitative results do not change.[10] In (4), possibly different critical levels are assigned to the two species. This is made necessary because of different life expectancies for the two species; the different α's are critical levels of lifetime utilities. See section V for a discussion of the choice of α_P.

In the case of two populations, an increase in α_H never raises and usually decreases the optimal number of humans, and an increase in α_P never raises and usually decreases the optimal number of pigs. These results are true whether or not the other population size is fixed or chosen optimally. (See the appendix, Lemma 1, for a formal proof.)

A simple example illustrates the application of critical-level utilitarianism to practical ethical questions involving animals. At the University of British Columbia, mice are used to produce monoclonal antibodies:[11] they are given tumours in their stomachs which grow the antibodies. One mouse can live through a maximum of three 'rounds' of antibody growth and removal. It seems reasonable to suggest that these mice are below neutrality, but are no worse off in the second and third rounds than in the first.

The ethical question is: should the suffering of individual mice be limited by shortening their lives to a single round? This move is an improvement for each mouse because it is below neutrality, but, if antibody production is to be the same, three times as many mice must be used.

Denoting x as the three-round case with n mice, utilities for each mouse in the three periods are (a, b, b), with $a \leqslant b < 0$. If y is the one-round case with $3n$ mice, each mouse's lifetime well-being is increased to $a (a < 0)$.

Critical-level utilitarianism declares x to be better than y if and only if

$$\begin{aligned} & V_\alpha(x) > V_\alpha(y) \\ & \leftrightarrow n(a + 2b - \alpha_M) > 3n(a - \alpha_M) \\ & \leftrightarrow a + 2b - \alpha_M > 3a - 3\alpha_M \\ & \leftrightarrow 2a - 2b - 2\alpha_M < 0 \\ & \leftrightarrow (a - b) - \alpha_M < 0, \end{aligned} \tag{5}$$

[9] In the case of a more general value function, we would require it to be symmetric in utilities. Equation (4) does not demand that other species consume at human levels. Presumably, theatre tickets and expensive meals produce little happiness for non-human animals, and, therefore, (4) does not demand that they consume these luxuries.

[10] In fact, assigning lower weights to pigs is mathematically the same as endowing them with different utility functions together with a scaled-down α_P. Hence the fact that pigs in (4) have different utility functions could also be interpreted as different weights if one chose to do so.

[11] This example is a simplified version of reality, and we are indebted to James Love for suggestions and advice.

which is true, because $(a-b) \leqslant 0$ $(a \leqslant b)$, and because the critical utility level for mice, α_M, is positive. Thus, the three-round case is ethically superior to the one round case because of the smaller population of mice. This result holds as long as the mice do not suffer more in rounds two and three than in the first $((a-b) \leqslant 0)$; a and b may be above neutrality.

III. ANIMALS IN RESEARCH

In this section, we present a simple general equilibrium model in which animals (guinea pigs) are used in research. Although the research promotes human well-being, the animals can be made better off (or worse off) – above some lower bound – by the expenditure of additional funds on their well-being. For example, it is well-known that guinea pigs are happier when they have cleaner and/or larger cages. Cleaning requires labour which could be used elsewhere, larger cages cost more money than smaller ones and, in addition, they take up more space, a scarce resource for which researchers actively compete.

To make the problem as simple as possible and to avoid obvious measurement problems, we assume that a given amount of research, R, is to be done and that the human population size, n_H, is fixed. We assume that the number of guinea pigs used in research can be reduced by increasing the amount of other resources devoted to research. Examples of research techniques that do not use live animals are tissue culture and computer modelling.[12] In our model, only guinea pigs and human labour are used in the research activity and hence they are assumed to be substitutes for each other.

This constraint is written

$$R = H(L_R, n_P) \tag{6}$$

where R, the amount of research, is constant, L_R is labour allocated to research, and n_P is the number of guinea pigs measured as a continuous variable. H is assumed to be increasing, continuously differentiable and strongly quasi-concave (see Fig. 1). The substitution possibilities described by (6) do not, of course, reduce the number of pigs used in any experiment below the level needed for statistical significance. Any such reduction would be condemned by any ethical theory that accords animals moral standing.

Because R and n_H are constants, they may be suppressed, and L_R in (6) may be solved for and written as

$$L_R = h(\sigma_H), \tag{7}$$

where h is decreasing, continuously differentiable and strongly convex, and where $\sigma_H = n_P/n_H$ (see Fig. 1).

Guinea pigs used in research have identical utility functions that depend only on the amount of food each one eats (g_P). Thus,

$$u_P = W(g_P), \tag{8}$$

where, W is increasing, continuously differentiable and strongly concave. Equation (8) implicitly assumes that all experimental subjects experience the same pain, suffering, and shortening of life.

[12] See, for example, Simpson (1983) or Stark and Shopsis (1983).

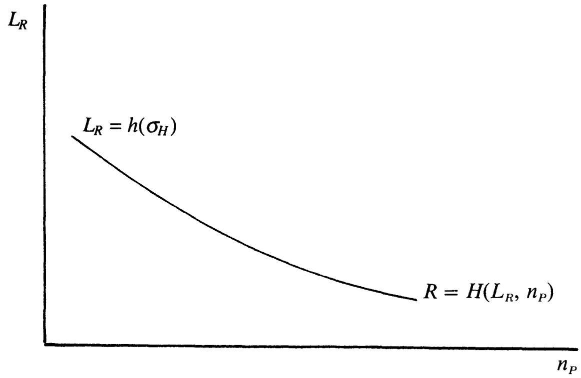

Fig. 1.

We assume that guinea pigs must eat a minimum amount of grain ($\underline{g}_P$) in order to be healthy enough to be good experimental subjects. Thus, research constraints are (7) and

$$g_P \geqslant \underline{g}_P. \tag{9}$$

We assume in addition that, at a consumption level of $\underline{g}_P$, the lifetime utility level of experimental subjects is below the critical level; that is, $W(\underline{g}_P) < \alpha_P$.

In this model, human well-being depends only on food consumption and the level of research, and the utility function for each person may be written as

$$u_H = \bar{U}(g_H, R), \tag{10}$$

where g_H is grain consumed by each person. Because the level of research output is fixed, only changes in the consumption of grain affect human utility, which is given by

$$u_H = U(g_H) \coloneqq \bar{U}(g_H, R) \tag{11}$$

where U is, by assumption, increasing, continuously differentiable, and strongly concave.

Grain is produced by human labour only. The grain production function is

$$G = f(L_G), \tag{12}$$

where L_G is labour allocated to grain production. Full employment requires

$$L_G + L_R = n_H. \tag{13}$$

Hence, (12) may be rewritten (using (13)) as

$$G = f(n_H - L_R). \tag{14}$$

For simplicity and mathematical convenience, we assume that grain is produced with constant returns to scale. Hence, (14) can be written as

$$G = w(n_H - L_R), \tag{15}$$

where w is a constant. Using (7) this can be rewritten as

$$\begin{aligned} G &= w[n_H - h(\sigma_H)] \\ &= n_H k(\sigma_H), \end{aligned} \tag{16}$$

where we have defined

$$k(\sigma_H) := (w/n_H)\,[n_H - h(\sigma_H)]. \tag{17}$$

k is increasing, continuously differentiable, and strongly concave (Fig. 2). Normalising the price of grain to 1, competition ensures that the real wage is equal to w.

Humans and guinea pigs share the food produced, so that

$$n_H g_H + n_P g_P = G = n_H k(\sigma_H); \tag{18}$$

remembering that $\sigma_H = n_P/n_H$ permits us to rewrite (18) as

$$g_H = k(\sigma_H) - \sigma_H g_P. \tag{19}$$

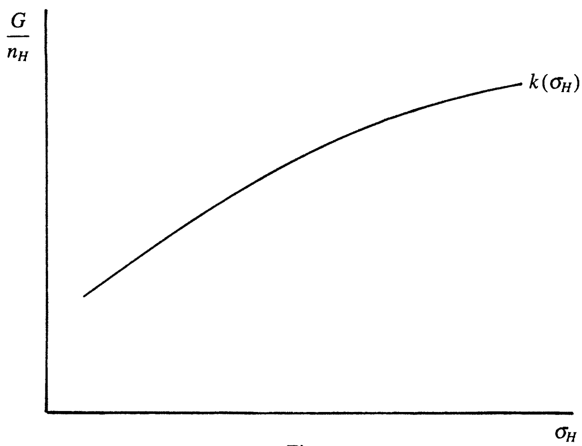

Fig. 2.

We first investigate the social outcome when investigators are cost minimisers without regard to the well-being of their animal subjects. We do not, of course, suggest that all or even most researchers exhibit this behaviour, but suggest that there are market and social forces (granting institutions) that pull in this direction. Researchers obtain grants on the basis of past performance as measured by their publications. Expenditures on the animals that bring their well-being above the minimum necessary to carry out the experiment reduce the funds available for continued research. This presumably reduces the research output of the scientist and hence affects his or her chances of obtaining further funding.

The cost of research is

$$wL_R + n_P g_P. \tag{20}$$

From (7) and (17) we find that

$$L_R = n_H[1 - w^{-1}k(\sigma_H)]. \tag{21}$$

In addition, cost minimisation ensures that $g_P = \underline{g}_P$ and hence – using (21) – that research cost is given by

$$wL_R + n_P \underline{g}_P = n_H[w - k(\sigma_H) + \sigma_H \underline{g}_P]. \tag{22}$$

Minimisation requires – assuming an interior solution – that

$$k'(\sigma_H^c) = \underline{g}_P. \qquad (23)$$

The solution is illustrated in Fig. 3; it allocates resources to maximise human utility (average and/or total because the human population is fixed).

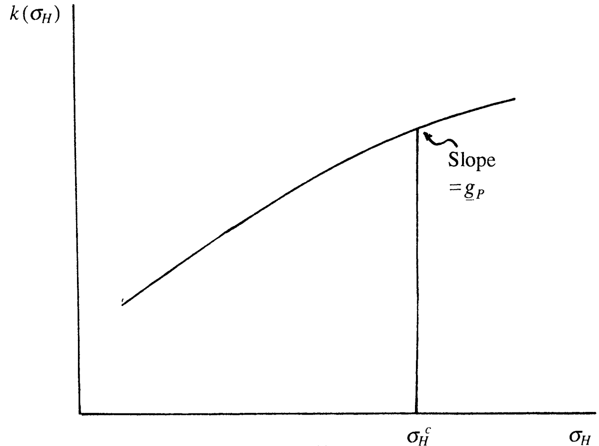

Fig. 3.

We now compare this to a 'first-best' outcome, where $g_P = g_P^f$ and $\sigma_H = \sigma_H^f$ are chosen to maximise

$$n_H(u_H - \alpha_H) + n_P(u_P - \alpha_P) = n_H[U(g_H) - \alpha_H] + n_P[W(g_P) - \alpha_P]$$

$$\overset{\circ}{=} U[k(\sigma_H) - \sigma_H g_P] + \sigma_H[W(g_P) - \alpha_P], \qquad (24)$$

where the second line of (24) follows from (19), subject to $g_P \geqslant \underline{g}_P$ and $\overset{\circ}{=}$ means 'is ordinally equivalent to'. There are three possible solutions.

Case f(i): $\sigma_H^f = 0$.

This case, in which animal experiments are not morally acceptable, is associated with higher values of α_P, higher values of $\underline{g}_P$, and a technology that permits all research to be done without animals and without excessive resource costs.

Case f(ii): $\sigma_H^f > 0$ and $g_P^f = \underline{g}_P$.

This case is mathematically equivalent to the second-best case, and we therefore postpone our discussion.

Case f(iii): $\sigma_H^f > 0$ and $g_P^f > \underline{g}_P$.

The third and perhaps the most interesting outcome has $n_P^f > 0$ and $g_P^f > \underline{g}_P$. In this case, the first-order necessary conditions for a maximum at g_P^f and σ_H^f are

$$U'(g_H^f) = W'(g_P^f) \qquad (25)$$

and $$U'(g_H^f)\,[k'(\sigma_H^f)-g_P^f]+W(g_P^f)-\alpha_P = 0. \tag{26}$$

Equation (25) requires the marginal utility of grain to be the same for pigs and people, but (of course) does not require equal utilities for the two groups. Equation (26) can be rewritten as

$$k'(\sigma_H^f) = g_P^f + \frac{[\alpha_P - W(g_P^f)]}{U'(g_H^f)} \tag{27}$$

and hence we can see that $$k'(\sigma_H^f) = g_P^f \tag{28}$$

if and only if $W(g_P^f) = \alpha_P$.

Suppose that $W(g_P^f) < \alpha_P$; then it is easy to demonstrate that

$$\sigma_H^f < \sigma_H^c \tag{29}$$

unambiguously. This is illustrated in Fig. 4 and the argument proceeds as follows. In that figure, $\tilde{\sigma}_H$ is chosen to make $k'(\tilde{\sigma}_H) = g_P^f$. Concavity and the hypothesis that $g_P^f > \underline{g}_P$ imply that $\tilde{\sigma}_H < \sigma_H^c$. Because $W(g_P^f) < \alpha_P$, the right side of (27) is greater than g_P^f, and so $k'(\sigma_H^f) > k'(\tilde{\sigma}_H)$; concavity yields $\sigma_H^f < \tilde{\sigma}_H$. Therefore, $\sigma_H^f < \sigma_H^c$ as claimed.

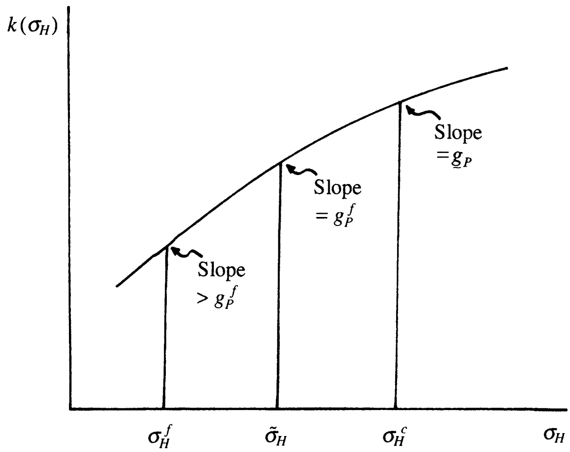

Fig. 4.

If $W(g_P^f) > \alpha_P$, then $\sigma_H^f > \tilde{\sigma}_H < \sigma_H^c$ so the two oppose each other and σ_H^f and σ_H^c cannot be compared with theoretical information alone.

A second-best solution to the ethical problem accepts $g_P = \underline{g}_P$ as a constraint. Hence, σ_H^s is chosen to maximise (24) with $g_P = \underline{g}_P$. In that case, the first-order condition is

$$k'(\sigma_H^s) = \underline{g}_P + \frac{[\alpha_P - W(\underline{g}_P)]}{U'(g_H^s)}. \tag{30}$$

Second-best grain consumption by humans, g_H^s, is found from

$$g_H^s = k(\sigma_H^s) - \sigma_H^s\,\underline{g}_P. \tag{31}$$

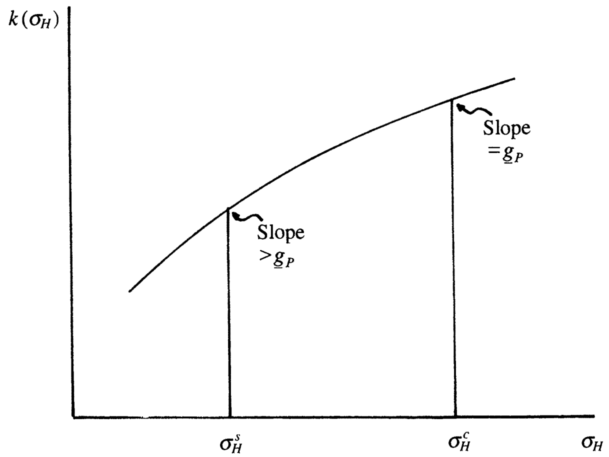

Fig. 5.

This solution is illustrated in Fig. 5, for the normal case where $W(\underline{g}_P) < \alpha_P$. The right side of (30) is greater than $\underline{g}_P$, so $k'(\sigma_H^s) > \underline{g}_P$, and – using concavity – $\sigma_H^s < \sigma_H^c$. Thus, the ethical consequence of $W(\underline{g}_P) < \alpha_P$ is that the cost-minimising use of guinea pigs is too great.

If $g_P^f > \underline{g}_P$ and $W(g_P^f) < \alpha_P$, then the second-best and first-best levels of σ_H may be compared. In this case, $\sigma_H^f > \sigma_H^s$ (Theorem 1; see the appendix). The higher standard of living for pigs permits a move toward the cost-minimising level of animal-intensity.

Assuming that $W(\underline{g}_P) < \alpha_P$, the results of this section may be summarised as follows:

The optimal level of animal use in research is *lower* than the cost-minimising level (and possibly zero) unless the optimal utility level for guinea pigs exceeds the critical level, with $W(g_P^f) > \alpha_P$.

The second-best level of animal use – the utility level for pigs is determined by cost minimisation – is lower than the cost-minimising level.

The optimal utility level for pigs cannot be achieved by a tax on their use if it exceeds the cost-minimising level $(W(g_P^f) > W(\underline{g}_P))$. In that case, direct controls are necessary.

The ethical objection to animal research – at current levels at least – rests on the claim that the pain, suffering, and life-shortening that experimental animals experience is not or cannot be compensated for by the gains to humans. It is possible, in our model, to illustrate this view by allowing for shifts in the utility function for guinea pigs. Writing

$$W(g_P) = \overline{W}(g_P) + \delta, \tag{32}$$

where $\overline{W}$ is fixed, δ is a shift parameter that increases when experimental conditions improve, and decreases when they worsen.

The value function (24), may be rewritten as:

$$n_H(u_H - \alpha_H) + n_P(u_P - \alpha_P) = n_H[U(g_H) - \alpha_H] + n_P[W(g_P) - (\alpha_P - \delta)]. \tag{33}$$

Equation (33) shows that an increase (decrease) in δ is mathematically equivalent to a decrease (increase) in α_P. Lemma 1 in the appendix establishes that the optimal number of pigs never decreases, and may increase as δ rises. If the optimal level of n_P is zero, then an increase in δ may leave it at zero. If the optimal level is positive then, given our concavity assumptions, a decrease in δ always decreases it if substitution is possible.[13] This result is true in both the first-best and second-best cases. Thus, the claim that the loss of animal well-being caused by research provides an ethical case against animal-intensive research is correct.

α_P is an important ethical parameter in the value function V_α. It expresses a concern for the lifetime well-being of individual animals, and places a floor on the trade-off between average utility and numbers. We show, in Theorem 2 in the appendix, that, in the first-best case, the optimal level of grain consumption for pigs, and, therefore, their level of well-being, increases when α_P increases if the pigs' utility level is greater than α_P, and decreases as α_P increases if the utility level is less than α_P. This result might seem somewhat counterintuitive, and it depends critically on the assumption that the level of research is fixed.

When α_P is zero, the utility level for pigs may be positive or negative. If it is positive, then g_P^f increases as α_P moves up from zero. It is possible that, for some α_P greater than zero, the first-best utility level equals α_P. Further increases in α_P decrease g_P^f and, therefore, the optimal level of well-being of the guinea pigs. If the pigs' utility level is negative when α_P is zero, then it falls (as does the number of pigs) as α_P rises.

IV. ANIMALS AS FOOD

The consumption of animals for food has population consequences and hence social consequences. Specifically, the population of food animals would be reduced if they were not consumed. If the (competitive) supply curve of pork (say) is elastic, then individual decisions for vegetarianism lower the pig population, and, of course, social decisions for vegetarianism would reduce the population as well.[14]

If vegetarian behaviour reduces the number of food animals (possibly to zero), then resources will be released. These may be used in producing other goods or services or they may be given to non-human animals. Because land is used to produce animal food, total land use in food production may fall and the land may be taken over by wild plants and animals. Alternatively, the resources may be used to increase the birth rate and, therefore, the human population size.

We consider the simplest model that is consistent with the connection between vegetarianism, food-animal population size, and the consumption of resources (in the form of food) by food animals. We then evaluate alternative

[13] In this case, the maxima are unique, and the inequalities in the proof of Lemma 1 are strict.

[14] In the case that a supply curve is perfectly inelastic, as might be the case with a regulated fishery, individual decisions will change neither the harvest nor the population. Instead, a pecuniary external economy to other consumers will result (a lower price).

states of the world – that is, alternative institutional arrangements – by means of the social value function presented in equation (4).

Our model has only two species, people and pigs, and two goods, grain and pork. The model ignores wild animals and the utility and numbers costs to them of farming. The human population is assumed to be fixed (for simplicity), and the model is static (a single period).

The number of people is a constant n_H, and grain production depends only on the number of people in grain farming and is represented by a production function f. Grain is used for two purposes: feeding pigs, and feeding people directly. Grain is the only resource used in raising pigs and should be interpreted as a proxy for resource use in general.

Therefore, given full employment, total grain production is $f(n_H)$, a constant denoted G. We assume that g_P, the amount of grain consumed by each pig must be at least $\underline{g}_P$ ($\underline{g}_P > 0$), and that additional grain for each pig contributes to well-being (utility) but not to weight or pork production. As long as $g_P \geqslant \underline{g}_P$, then, pork production can be measured by n_P, the population of pigs. For simplicity, n_P is treated as a continuous variable. Assuming that each human consumes g_H units of grain, the production constraints for the economy are, therefore,

$$g_P \geqslant \underline{g}_P \tag{34}$$

and

$$n_H g_H + n_P g_P \leqslant f(n_H) = G. \tag{35}$$

We assume that $\underline{g}_P$ is small enough relative to $G = f(n_H)$ so that there are many solutions to (34) and (35).

Humans consume both grain and pork and we assume that all have the same preferences, represented by the utility function U (which is increasing, twice continuously differentiable, and strongly concave). Each person's utility level is

$$\begin{aligned} u_H &= U\left(g_H, \frac{n_P}{n_H}\right) \\ &= U(g_H, \sigma_H), \end{aligned} \tag{36}$$

where $\sigma_H = n_P/n_H$ is pork per person. Pork is assumed to be a normal good for humans. Pigs consume grain, and their utility levels are

$$u_P = W(g_P), \tag{37}$$

where W is increasing, twice differentiable, and strongly concave.

The social value function corresponding to (4) is

$$\begin{aligned} n_H(u_h - \alpha_H) + n_P(u_P - \alpha_P) &= n_H\left[U\left(g_H, \frac{n_P}{n_H}\right) - \alpha_H\right] + n_P[W(g_P) - \alpha_P] \\ &= n_H\{U(g_H, \sigma_H) - \alpha_H + \sigma_H[W(g_P) - \alpha_P]\}, \end{aligned} \tag{38}$$

where $\alpha = (\alpha_H, \alpha_P)$ and $\sigma_H = n_P/n_H$. Because n_H, the human population, is fixed, (38) is ordinally equivalent to ψ_{α_P} as given by

$$\psi_{\alpha_P}(g_H, \sigma_H, g_P) = U(g_H, \sigma_H) + \sigma_H W(g_P) - \sigma_H \alpha_P. \tag{39}$$

In this notation the constraint, (35), becomes

$$g_H + \sigma_H g_P \leqslant \frac{f(n_H)}{n_H} = \frac{G}{n_H} =: \bar{G}. \tag{40}$$

We consider three different ways that g_H, σ_H and g_P might be chosen. The first is the competitive market, with equal incomes for all humans. This provides a benchmark for two possibilities based on the ethics in (39). The second is the choice of g_H, σ_H, and g_P, that maximise $\psi_{\alpha_P}(g_H, \sigma_H, g_P)$ subject to constraints (34) and (40). The third is the second-best solution. It accepts the market's choice of g_P as given, and then chooses g_H and σ_H (human consumption) optimally, subject to the additional constraint.

The competitive solution, $(g_H^c, \sigma_H^c, g_P^c)$, is easy to characterise. First, cost minimisation ensures that

$$g_P^c = \underline{g}_P, \tag{41}$$

because the cost of production per pig is $p \times g_P$ where p is the price of grain. We normalise this price to one, and denote the (relative) price of pork by q. The long-run competitive equilibrium (zero-profit equilibrium) price of pork is

$$q^c = \underline{g}_P. \tag{42}$$

The constraint facing humans is given by

$$g_H + \sigma_H \underline{g}_P = \bar{G}, \tag{43}$$

and it is illustrated in Fig. 6. C is the competitive outcome for each person, and at (g_H^c, σ_H^c), the marginal rate of substitution between pork and grain is equal to $\underline{g}_P$, the minimum cost of producing pork; that is,

$$MRS^H_{\sigma_H, g_H} = \frac{U_\sigma(g_H^c, \sigma_H^c)}{U_g(g_H^c, \sigma_H^c)} = q^c = \underline{g}_P, \tag{44}$$

where subscripts on U denote partial derivatives. (Remember that the price of grain has been normalised to one.) We assume that both g_H^c and σ_H^c are positive. Competitive equilibrium maximises each person's utility subject to constraints (34) and (40). Because pigs' utilities are ignored, it does not maximise social utility as given by (39): $\psi_{\alpha_P}(g_H, \sigma_H, g_P)$.

Although pigs do not have access to markets, the competitive equilibrium is Pareto-efficient: it is impossible to increase any individual's (including pigs) well-being without decreasing another's well-being. It is not the case, however that other Pareto-efficient allocations can be decentralised as competitive equilibria: the second theorem of welfare economics does not hold.

Next we turn to the problem of choosing (g_H, σ_H, g_P) to maximise $\psi_{\alpha_P}(g_H, \sigma_H, g_P)$ subject to (34) and (40). We denote the optimal values (the first-best solution) as $(g_H^f, \sigma_H^f, g_P^f)$, and discuss three cases.

Case f(i): $\sigma_H^f = 0$.

This can occur, even with $\sigma_H^c > 0$. It is associated with higher values of α_P, higher values of $\underline{g}_P$, or a weak human preference for pork.

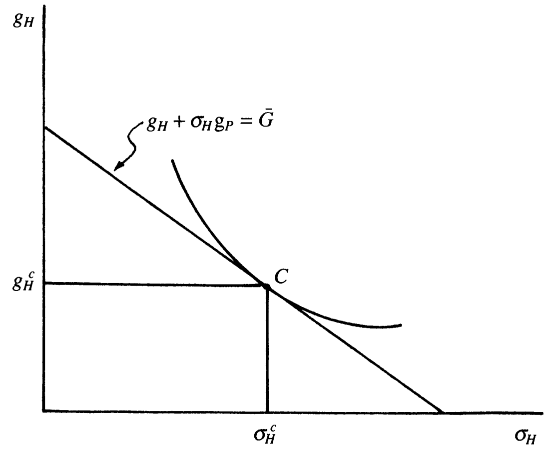

Fig. 6.

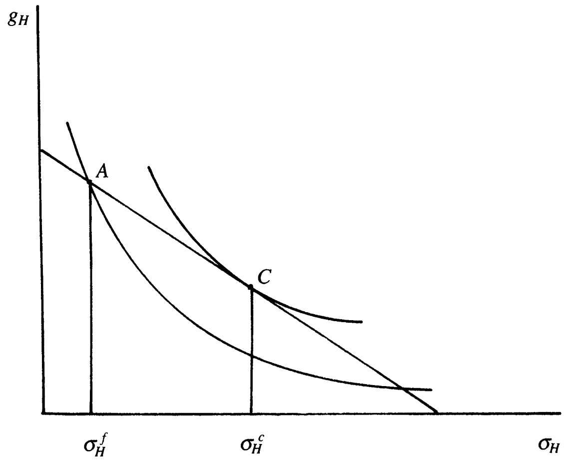

Fig. 7.

Case f(ii): $g_P^f = \underline{g}_P$ and $\sigma_H^f > 0$.

Assuming $g_H^f > 0$, g_H^f and σ_H^f must maximise $\psi_{\alpha_P}(g_H, \sigma_H, \underline{g}_P)$ subject to (43), and first-order conditions require that

$$\frac{U_\sigma(g_H^f, \sigma_H^f)}{U_g(g_H^f, \sigma_H^f)} = \underline{g}_P + \frac{(\alpha_P - \underline{u}_P)}{U_g(g_H^f, \sigma_H^f)}, \tag{45}$$

where $\underline{u}_P = W(\underline{g}_P)$, the minimum utility for pigs.

The main factual claim for those who argue for vegetarianism is that $\underline{u}_P < \alpha_P$. If this is true, then

$$MRS^H_{\sigma_H, g_H} = \frac{U_\sigma(g_H^f, \sigma_H^f)}{U_g(g_H^f, \sigma_H^f)} > \underline{g}_P \tag{46}$$

and (43) must be satisfied. This outcome is illustrated in Fig. 7. Because of the inequality in (46), A, the best outcome in this case, lies to the North-West of C, and so

$$\sigma_H^f < \sigma_H^c, \tag{47}$$

which indicates that the optimal solution with $g_P^f = \underline{g}_P$ requires lower pork consumption. Remembering that $\sigma_H = n_P/n_H$, this requires a smaller population of pigs than is provided by the competitive solution to the problem.

Case f(iii): $g_P^f > \underline{g}_P$ and $\sigma_H^f > 0$.

The first-order conditions in this case are

$$U_g(g_H^f, \sigma_H^f) = \lambda^f, \tag{48}$$

$$U_\sigma(g_H^f, \sigma_H^f) + W(g_P^f) - \alpha_P = \lambda^f g_P^f, \tag{49}$$

$$W'(g_P^f) = \lambda^f, \tag{50}$$

and (40), where λ^f is the optimal value of the Lagrange multiplier associated with the constraint (40). Equations (48) and (50) together yield

$$U_g(g_H^f, \sigma_H^f) = W'(g_P^f) \tag{51}$$

which requires the marginal utility of grain to be the same for humans and pigs. (The special case discussed above with $g_P^f = \underline{g}_P$ requires the marginal utility of grain for people to exceed the marginal utility of grain for pigs when $g_P = \underline{g}_P$ because transfers of grain from pigs to people are not feasible in this case.) (48) and (49) may be combined to yield

$$MRS_{\sigma_H, g_H}^H = \frac{U_\sigma(g_H^f, \sigma_H^f)}{U_g(g_H^f, \sigma_H^f)} = g_P^f + \frac{[\alpha_P - W(g_P^f)]}{U_g(g_H^f, \sigma_H^f)} \tag{52}$$

and

$$g_H^f + \sigma_H^f g_P^f = \bar{G}. \tag{53}$$

These conditions contain a term $[\alpha_P - W(g_P^f)]$ which cannot be signed *a priori*, even if pigs are badly off in the competitive economy. That is, even if $W(\underline{g}_P) = \underline{u}_P < \alpha_P$, it is possible that $W(g_P^f) > \alpha_P$.

If α_P is greater than zero, however, and the length of life of pigs is shorter than it might be, then utility per day must make up for the shorter life. Further, if food animals are normally kept in stalls and cages in the first-best solution, u_P^f is kept down. We believe, therefore, that the first-best solution is likely to be characterised by the inequality

$$u_p^f = W(g_P^f) < \alpha_P. \tag{54}$$

This outcome is illustrated in Fig. 8. The 'price' of pork to humans is increased to $g_P^f > \underline{g}_P$, and this makes the 'budget line' swing inward. Starting at the competitive equilibrium, humans, facing price g_P^f would move to Q. Assuming that pork is a normal good to humans, the quantity of pork consumed at Q, $\tilde{\sigma}_H$, is less than at C, the competitive equilibrium, $(\tilde{\sigma}_H < \sigma_H^c)$. If the critical level for pigs, α_P, is greater than the utility level for pigs corresponding to the higher grain consumption, $W(g_P^f)$, then (from (48)) consumption at B (the social optimum) must be less than consumption at Q, and therefore less

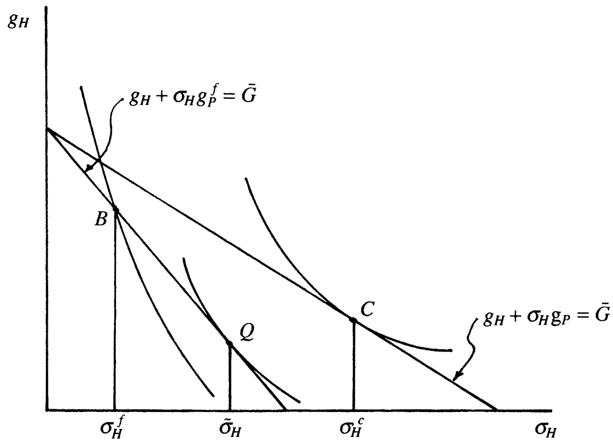

Fig. 8.

than consumption at the competitive outcome; that is, $\sigma_H^f < \tilde{\sigma}_H < \sigma_H^c$. Remembering the definition of σ_H, this implies that $n_P^f < n_P^c$.

On the other hand, if $W(g_P^f) > \alpha_P$ so that pigs utilities are raised above the critical level, B will not lie to the northwest of Q but, instead, will lie to the southeast. In that case, σ_H^f cannot be compared to σ_H^c. The reason is that there are two things that work in opposite directions. The first is that a high value of g_P ($g_P^f > \underline{g}_P$) raises the (opportunity) cost (of pork) to humans. For every pig, they must give up g_P^f units of grain. This effect tends to decrease σ_H. On the other hand, a high value of g_P can raise pigs' utilities above the critical level. This means that an increase in the number of pigs increases value $\psi_{\alpha_P}(g_H^f, \sigma_H^f, g_P^f)$, and this tends to increase σ_H.

Can the optimal levels $(g_H^f, \sigma_H^f, g_P^f)$ be achieved by a system of taxes and/or subsidies? If an excise tax on pork is used (with tax proceeds paid back as a lump sum), it can increase the 'price' of pork to consumers, and thus decrease pork consumption. But the well-being of pigs would stay at the minimum value of $W(\underline{g}_P)$, the utility level corresponding to the competitive level of g_P, the minimum necessary for raising them. It follows that, if the optimal amount of grain per pig is above the minimum ($g_P^f > \underline{g}_P$), direct controls are necessary.

The second-best solution is characterised by taking the competitive solution for the grain consumption of the pigs, $g_P^c = \underline{g}_P$, as given and then choosing g_H and σ_H to maximise (39). In case f(ii) above, the first-best solution actually sets $g_P^f = g_P^c = \underline{g}_P$. Hence, the first-best solution characterised by (45), (46) and (47) above also characterises the second-best solution. In this case, as in case f(ii) above, pork production and the pig population are too high in competitive equilibrium.

If the second-best solution is to be implemented, a tax on pork consumption can be used to reduce pork consumption below the competitive level (as long as the competitive level of pig well-being is below the critical level, with $W(\underline{g}_P) < \alpha_P$).

Assuming that $W(\underline{g}_P) < \alpha_P$, the results of this section may be summarised as follows:

The optimal level of pork consumption is lower than the competitive market level (and possible zero) unless the optimal utility level for pigs exceeds the critical level, with $W(g_P^f) > \alpha_P$.

The second-best level of pork consumption – in which the utility level for pigs is determined by the market – is lower than the competitive market level.

The optimal level of utility for pigs cannot be achieved by a taxation scheme if it exceeds the competitive market level ($W(g_P^f) > W(\underline{g}_P)$). In that case, direct controls are necessary.

An interesting ethical problem arises in the case of animals, such as cows, that are kept in order to produce food for humans but are not killed when young. This means, if these animals are above neutrality, that one source of low utility levels for farm animals, short lifespans, is absent. Thus, it may be true that the consumption of dairy products is ethically preferable to meat consumption.

Although it is somewhat implausible, it is theoretically possible that, in cost-minimising farms, animal levels of well-being are greater than α_P ($W(\underline{g}_P) > \alpha_P$). In this case, food animals are a source of value, and meat eating has positive social consequences beyond the enjoyment of humans. In this case, other actions that promote pigs' well-being and/or numbers would have good consequences as well. It does not follow, however, that humans have a moral-obligation to sacrifice most of their own happiness to attain these good results. Such actions, while morally permissible, are supererogatory – beyond the call of duty.

V. ALTERNATIVE ETHICAL APPROACHES

In this section, we examine some ethical principles that confer moral standing on sentient non-human animals. We argue that welfarist principles of the kind we have employed are more satisfactory for this purpose than rival moral positions.

Utilitarians typically recognise animal well-being as part of the total, extending their calculations 'to the whole sentient creation' (Mill, 1962, p. 263). There are, of course, many versions of utilitarianism, and the diversity is increased when the evaluation of different population sizes is considered.

Critical-level utilitarianism is a general principle for the evaluation of population size that encompasses many specific ones, one for each choice of the critical level(s) α. In each case, the well-being of each individual, human or not, is given equal weight, thus satisfying Singer's (1975, 1979, 1980) axiom of 'equal consideration of interests'. If the critical levels are zero, classical utilitarianism results, and in that case a single individual living ten years (say) at a given utility level in each year is ethically equivalent to two individuals who live five years each at the same annual level. Positive levels of α prefer the former state to the latter, thus giving explicit weight to individual lives as well as utilities. Higher levels of α sharpen and place a floor on the tradeoff between numbers and average utilities, making it more difficult to substitute numbers for average utility. Critical-level utilitarianism and related welfarist principles are roughly consistent with the welfarist approach of Singer (1975, 1979, 1980).

The choice of the critical levels $\alpha = (\alpha_H, \alpha_P)$ makes a difference to the optimal arrangement in both our models, and this suggests that they cannot simply be chosen arbitrarily. A possible choice for animals is the average level of lifetime well-being that an individual in the species or a closely related species could expect to enjoy in its natural habitat.[15] This view, however may face a philosophical difficulty. The argument for a positive α_H, the critical level for humans, is that people are sentient beings who are cognisant of their futures and pasts, make plans, and pay attention to memories, in addition to experiencing pains and pleasures. Cognition of future and past is present in animals such as gorillas and chimpanzees, but it seems likely that simpler animals, such as mice and rats, have less coherent lives. Indeed, animals with rudimentary brains, such as fish and oysters, appear to exist in the present only. This view suggests that setting α_P at the 'natural' level is appropriate for highly sentient animals, but for species whose members enjoy less united lives, a lower critical level is reasonable, with a level of zero used for species whose members experience the present only.[16]

A competing welfarist principle is average utilitarianism; it values alternative states for a single species. Its employment for more than one species is somewhat unclear, however. If the value function is an aggregate of the separate average utilities of pigs and people, then, in general, the principle of equal consideration of interests is violated. If, on the other hand, the average is taken across both species, much of the ethical appeal of the principle is lost. We have shown, however, that in simple population problems, the employment of critical-level utilitarianism with higher values of α leads to the solution that is optimal according to average utilitarianism (Blackorby and Donaldson, 1984).

There are alternatives to critical level utilitarianism which also avoid the problems of classical utilitarianism. Hurka (1983) has suggested that the value function should approximate average utility for large populations and total utility for small n (a mathematical example is given in Blackorby and Donaldson (1984)). Ng (1986) has suggested a principle he calls number-damped total utilitarianism which includes critical-level utilitarianism as a special case. In general, however, these rules are subject to the difficulties that average utilitarianism encounters when extended to multiple species.

It is possible to argue that killing animals for food and experimenting on them has deleterious effects on human character, leading to less respect for life and to harmful behaviour. Because such behaviour affects well-being, it is possible to incorporate concerns like this into a welfarist argument but our models do not, of course, take account of it.

A theory of social justice and morality based on the idea of contract is offered by Rawls (1971), and it is one of many theories of this type. Rawls admits,

[15] This suggestion is consistent with the view of Rolston (1988, ch. 2).

[16] We are indebted to John Broome and Gary Wedeking for this argument. Broome takes the view that 'people have coherent lives tied together by plans and memories, but pigs do not', and argues that α_P should be zero. Wedeking takes the more flexible position presented in the text.

however, that contract theories provide 'no account... of right conduct in regard to animals and the rest of nature' (p. 512), and suggests that 'a conception of justice is but one part of a moral view' (p. 512). Possible candidates for supplemental theories are welfarist ones like critical-level utilitarianism and rights-based theories.

Regan (1982, 1983) presents rights-based arguments for vegetarianism and against research on animals. He argues that sentient non-human animals have a right to respectful treatment, and that this right makes animal exploitation for food or knowledge morally illegitimate. Given such a moral prohibition, the fact that farming and research call forth animal populations that would not otherwise exist is not a problem. If, however, a rights theory were to allow for a trade-off of animal rights against significant benefits to humans (from research, say), then it could not deal with the population question without an explicit formulation of the trade-off.

This problem is encountered by Lesco's (1988) account of Buddhist ethics toward animals. He argues that the principle of *ahimsa* or no-harm – avoiding unnecessary suffering – leads to vegetarianism and to a prohibition of animal use in cosmetics testing, but allows some animal research – in vaccines, for example – because, when there is a trade-off between human and animal well-being, humans take precedence. Welfarist principles such as critical-level utilitarianism offer an explicit formulation of such ethics.

Not all religious ethics are as concerned with animal well-being as the Buddhist one, however. In the Biblical creation myth, humans are told to 'fill the earth and subdue it, rule over the fish in the sea, the birds of heaven, and every living thing that moves upon the earth' (New English Bible, 1970, Genesis 1: 28). This rule is, of course, to be consistent with God's will for animals, but little guidance is offered. Later Christian writers argued that, because animals are part of the 'lower order of creation' (St. Augustine (1961, pp. 147–50), their well-being is less important than that of humans.

VI. CONCLUSION

The economic models we have employed are necessarily simplifications of reality, which omit consideration of several important aspects of the ethical problem. First, our models ignore the very important differences in the suffering of animals in different experimental situations and different farming techniques. Research situations vary from conditions that resemble clean zoos, with animals in family groups, to individually caged or restrained animals who experience physical, psychological, and social discomfort. Theoretical models can, however, make little contribution here. Experiments that subject animals to a great deal of suffering must, to be morally permissible, result in greater benefits than more benign experiments, but these must be assessed on a case by case basis. In university research, this is done by animal care committees.

A second weakness of our models is the omission of human inequality – preventing consideration of the argument that malnutrition and starvation can be voided by a switch to vegetarian diets, permitting plant food to be consumed directly by humans rather than first by animals and then by humans (Lappé, 1971); the latter arrangement requires much more grain production. This argument has a good deal of moral force. A similar argument, that meat production increases the amount of land under cultivation and therefore, contributes to the decline of wild animals and to global warming, is similarly ignored.

Even if animals are not granted moral standing, it is possible to produce an 'ethics' of animal exploitation by noting that humans care about animal suffering, and themselves are made worse off by it. This argument takes account of human sentiment for animal well-being. Thus animal well-being appears in the value function through human utility functions. We have no objection to this formulation of human utilities, but suggest that it is not a valid substitute for the recognition of the moral standing of all sentient creatures, regardless of whether they are liked or disliked by humans.

A significant problem in utilitarian and other welfarist ethics is the need to make inter-individual comparisons of gains and losses in well-being across species. Such comparisons are hard to make between members of our own species, and this activity has near taboo status among economists. Our qualitative results follow from the claim that such comparisons are meaningful or possible, in principle, but practical judgements demand approximate comparisons at minimum (see Dawkins (1980) for an overview of the literature on the measurement of animal welfare). The difficulty of making them may explain the prevalence of rules of thumb such as 'do no harm' or 'experimental animals should never be below neutrality'.

Partial answers to the questions posed in the introduction are:

- There is a case for raising animals for food, but it is possible that the ethical vegetarians are right that the optimal level of meat consumption is zero. Their case is strengthened by the fact that the taste for meat is not a 'brute fact' about humans but is influenced by acculturation and habituation. The same observation applies to animal use in cosmetics testing. The case for some animal use in medical research is much stronger, because the benefits may be very great. This does not mean, of course, that we should be complacent about present necessities.
- Given the above remarks, it is clear from the results of section IV that it is arguable that our diets should contain less meat than at present. This case is strengthened if farm-animal well-being is kept at profit-maximising levels (the second-best case) and if our ethics demand relatively high critical utility levels for animals (α_P). (Recall that a short but happy life may still be below α_P.)
- There is a strong case that unregulated research is too animal intensive. It is, of course, foolish to reduce animal numbers in a single study to the point of statistical insignificance, but the model of section III suggests that, overall, there should be more reliance on alternative research designs. This case is strengthened if the efforts of animal care committees in raising the levels of well-being of experimental animals are unsuccessful, and is also strengthened by relatively high critical levels for animals (α_P).
- Unless farm and experimental animals are given a reasonable standard of

living in order to produce the desired result, there is a case for direct regulation of farm animal well-being, through farm-animal rights legislation such as Sweden's (Lohr, 1988) and direct regulation of animal care in Universities (supervised in Canada by the Canadian Council on Animal Care and the individual Animal Care Committees). We believe that direct regulation should be extended to all animal use in private businesses as well. Because the benefits of cosmetic use are so trivial, the argument for the elimination of animal use in cosmetics testing is persuasive.

We can draw two policy conclusions from this work. The first is that direct regulation of animal care is a desirable activity and should be extended to all parts of the economy in which animal exploitation takes place. Because the benefits of meat-eating and cosmetics-wearing are conditioned by habituation, acculturation, and the desire to conform, the real costs of such regulation may be low.

The second policy conclusion concerns numbers. Regulations that affect the number of farm and research animals are as important, ethically, as those that affect their standard of living. It is tempting, given our simple models, to suggest that the numbers problem could be solved with a tax on each animal sold for food or used in research, one for each species, but such a tax would not be sufficient given the diversity of animal experience, especially in research.[17] We do suggest, however that a basic tax would provide an economic incentive to reduce numbers, and it could be of some help as a supplement to direct regulation of numbers in activities in which animal suffering is greater than average.

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Appendix

Lemma 1. *If $\hat{x}$ is optimal according to V_α (4) from a set of feasible states S when $\alpha_P = \hat{\alpha}_P$, and $\tilde{x}$ is optimal when $\alpha_P = \tilde{\alpha}_P$, then, given $\alpha_H = \bar{\alpha}_H$ in both cases,*

$$(\tilde{\alpha}_P > \hat{\alpha}_P) \rightarrow n^P(\tilde{x}) \leqslant n^P(\hat{x}), \tag{A 1}$$

where $n^P(x)$ is the optimal number of guinea pigs in x, $x \in S(n^P(x) = |N^P(x)|)$.

Proof. Because $\hat{x}$, $\tilde{x}$ are optimal in S,

$$\sum_{i \in N^H(\hat{x})} [U^i(\hat{x}) - \bar{\alpha}_H] + \sum_{j \in N^P(\hat{x})} [U^j(\hat{x}) - \hat{\alpha}_P]$$
$$\geqslant \sum_{i \in N^H(\tilde{x})} [U^i(\tilde{x}) - \bar{\alpha}_H] + \sum_{j \in N^P(\tilde{x})} [U^j(\tilde{x}) - \hat{\alpha}_P] \tag{A 2}$$

[17] A tax that is sensitive to animal well-being would probably work, but would require as much information as direct regulation does. Indeed, the setting of levels for such a tax might involve greater resource costs than direct regulation.

and

$$\sum_{i \in N^H(\tilde{x})} [U^i(\tilde{x}) - \bar{\alpha}_H] + \sum_{j \in N^P(\tilde{x})} [U^j(\tilde{x}) - \tilde{\alpha}_P] \geqslant \sum_{i \in N^H(\hat{x})} [U^i(\hat{x}) - \bar{\alpha}_H] + \sum_{j \in N^P(\hat{x})} [U^j(\hat{x}) - \tilde{\alpha}_P]. \quad (A\ 3)$$

Adding (A 2) and (A 3) and simplifying

$$-n^H(\hat{x})\,\bar{\alpha}_H - n^P(\hat{x})\,\hat{\alpha}_P - n^H(\tilde{x})\,\bar{\alpha}_H - n^P(\tilde{x})\,\tilde{\alpha}_P \geqslant -n^H(\tilde{x})\,\bar{\alpha}_H - n^P(\tilde{x})\,\hat{\alpha}_P - n^H(\hat{x})\,\bar{\alpha}_H - n^P(\hat{x})\,\tilde{\alpha}_P, \quad (A\ 4)$$

or

$$n^P(\hat{x})\,\hat{\alpha}_P + n^P(\tilde{x})\,\tilde{\alpha}_P \leqslant n^P(\tilde{x})\,\hat{\alpha}_P + n^P(\hat{x})\,\tilde{\alpha}_P, \quad (A\ 5)$$

so that

$$[n^P(\tilde{x}) - n^P(\hat{x})]\,(\tilde{\alpha}_P - \hat{\alpha}_P) \leqslant 0. \quad (A\ 6)$$

(A 1) is immediate. ■

THEOREM 1. *If* $g_P^f > \underline{g}_P$ *and* $W(g_P^f) < \alpha_P$, *then* $\sigma_H^f > \sigma_H^s$.

Proof. Set $g_P = \tilde{g}_P$ where $\underline{g}_P \leqslant \tilde{g}_P \leqslant g_P^f$ so that the first-order condition for choosing $\tilde{\sigma}_P$ to maximise

$$U[k(\sigma_H) - \sigma_H \tilde{g}_P] + \sigma_H[W(\tilde{g}_P) - \alpha_P] \quad (A\ 7)$$

is given by

$$U'[k(\tilde{\sigma}_H) - \tilde{\sigma}_H \tilde{g}_P]\,[k'(\tilde{\sigma}_H) - \tilde{g}_P] + [W(\tilde{g}_P) - \alpha_P] = 0. \quad (A\ 8)$$

Writing $\tilde{g}_H = k(\tilde{\sigma}_H) - \tilde{\sigma}_H \tilde{g}_P$ and taking the derivative of (A 8) with respect to $\tilde{g}_P$ yields

$$U''(\tilde{g}_H)\left\{[k'(\tilde{\sigma}_H) - \tilde{g}_P]^2 \frac{\partial \tilde{\sigma}_H}{\partial \tilde{g}_P} - \tilde{\sigma}_H\right\} + U'(\tilde{g}_H)\left[k''(\tilde{\sigma}_H)\frac{\partial \tilde{\sigma}_H}{\partial \tilde{g}_P} - 1\right] + W'(\tilde{g}_P) = 0, \quad (A\ 9)$$

so that

$$\frac{\partial \tilde{\sigma}_H}{\partial \tilde{g}_P}\left\{U''(\tilde{g}_H)\,[k'(\tilde{\sigma}_H) - \tilde{g}_P]^2 + U'(\tilde{g}_H)\,k''(\tilde{\sigma}_H)\right\} = U'(\tilde{g}_H) - W'(\tilde{g}_P) + \sigma_H U''(\tilde{\sigma}_H). \quad (A\ 10)$$

The term in braces on the left side of (A 10) is negative, and, because $W(\underline{g}_P) < W(g_P^f) < \alpha_P$, $U'(\tilde{g}_H) < W'(\tilde{g}_P)$ for all $\tilde{g}_P \leqslant g_P^f$. Therefore, the right side of (A 10) is negative, and $\partial \tilde{\sigma}_H / \partial \tilde{g}_P$ is positive for all $\tilde{g}_P$ in $[\underline{g}_P, g_P^f]$. Therefore, $\sigma_H^f > \sigma_H^s$. ■

THEOREM 2. *If* $g_P^f > \underline{g}_P$, *then*

$$\text{sign}\,\frac{dg_P^f}{d\alpha_P} = \text{sign}\,[W(g_P^f) - \alpha_P]. \quad (A\ 11)$$

Proof. The first-order condition (25) requires

$$U'(g_H^f) = W'(g_P^f), \quad (A\ 12)$$

which becomes, using (19),

$$U'[k(\sigma_H^f) - \sigma_H^f g_P^f] = W'(g_P^f). \quad (A\ 13)$$

Differentiating,

$$U''(g_H^f)\left\{[k'(\sigma_H^f) - g_P^f]\frac{\partial \sigma_H^f}{\partial \alpha_P} - \sigma_H^f \frac{\partial g_P^f}{\partial \alpha_P}\right\} = W''(g_P^f)\frac{\partial g_P^f}{\partial \alpha_P}, \quad (A\ 14)$$

and

$$\frac{\partial g_P^f}{\partial \alpha_P}\left[W''(g_P^f) + g_P^f U''(g_H^f)\right] = \frac{\partial \sigma_H^f}{\partial \alpha_P} U''(g_H^f)\,[k'(\sigma_H^f) - g_P^f]. \quad (A\ 15)$$

Using first-order condition (27), (A 15) becomes

$$\frac{\partial g_P^f}{\partial \alpha_P}\left[W''(g_P^f)+g_P^f\,U''(g_H^f)\right]=\frac{\partial \sigma_H^f}{\partial \alpha_P}\frac{U''(g_H^f)}{U'(g_H^f)}[\alpha_P-W(g_P^f)]. \tag{A 16}$$

Because W and U are strongly concave and increasing, $W''(g_P^f)$ and $U''(g_P^f)$ are negative and $U'(g_H^f)$ is positive. Further, from Lemma 1 and the discussion in the text, $\partial\sigma_H^f/\partial\alpha_P$ is negative. Equation (A 11) is immediate. ■

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