# ‘Please in My Back Garden’: When Neighbours Compete in the Provision of Local Environmental Public Goods

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## Introduction

This paper models the effort exerted by neighbouring individuals as they compete for an environmental commodity which exhibits the properties of a mixed public good. Our motivating example is the levels of seed that neighbours dispense when trying to attract birds to their individual gardens for private enjoyment.

Relying upon private contributions will typically result in an under-provision of a public good. This sub-optimality will be exacerbated the stronger the good exhibits aspects of non-excludability or non-rivalry in consumption, each of which create higher incentives to free-ride (Olson; 1971). The literature regarding the free-rider problem is vast, both in theoretical (Arnott & Small; 1994), empirical (Olson; 1971) and experimental (Andreoni; 1988, Weimann; 1994) fields. These papers typically describe a *pure* public good, yet there are many instances when an individual is able to derive a private utility stream through their act of contribution. These *impure* public goods, first coined by Samuelson (1954), may begin to partially offset the free-rider problem, as now individuals have a greater incentive to contribute.

The Impure Public Goods model is algebraically explored by Cornes & Sandler (1994). They illustrate that the extent to which the private element of an impure public good can tackle the free-rider problem largely hinges upon the degree of complementarity between its private and public aspects.

Previous empirical work by Brock, Perino & Sugden (2013) has revealed an interesting example where environmental interaction exhibits the attributes of an impure public good, namely the feeding of garden birds in local neighbourhoods. Survey responses suggest that individuals understand the public-goods benefits of feeding. These arise in the form of positive externalities from an increase in the bird population to the local neighbourhood and, one could argue, to the birds themselves. However, people state that the primary incentive for feeding is to view birds within the confines of their garden. The private and public benefits which arise in tandem from bird-feeding give a very nice instance of how a public good’s impurity can begin to alleviate free-rider tendencies.

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While impure public good characteristics can reduce the degree of under-provision, they can usually not achieve provision at the socially optimal level by private contributions alone. There will always be the public goods element that will not be internalised by private parties (*reference*?).

However, in the case of bird feeding there is an additional mechanism that can fundamentally change the nature of the game. In order to successfully construct a model which most accurately resembles our motivating example, we must introduce two further theories to operate in conjunction with Impure Public Goods Theory.

Birds can move freely and usually forage in territories greater than an individual's garden, yet a bird can only feed in one person's private garden at any given time. Ecology provides us with a neat way to model the way birds allocate their time within their foraging territory based on the spatial distribution of food within this area. Ideal Free Distribution theory is an ecological modelling technique which illustrates how animals employ Nash-equilibrium strategies in response to changes in food densities so as to maximise their survival and/or reproductive success.

These foraging strategies create a direct (strategic) link between the numbers of birds attracted by the food present in a given individual's private garden against that available in neighbouring areas. Contest Theory illustrates situations where individuals 'expend effort to increase their probability of winning a given prize' (Dixit; 1987). This theory nicely fits our bird-feeding model, with 'effort' characterised by the volume of seed an individual allots and birds constituting a 'prize' which can be distributed in proportion to effort. In order to procure the private utility that is derived from viewing birds in their own garden, neighbours therefore face a strategic situation similar to a Tullock-type contest. Contests typically create incentives for an overprovision of effort relative to the level which is deemed socially optimal. Such 'over-dissipation' (Konrad; 2009, p.55) is accentuated in experimental settings, where the extent to which respondents engage in the contest consistently exceeds the thresholds predicted by theory (Davis & Reilly; 1998).

Our model now fuses theories which offer contrasting predictions regarding the direction of inefficiency of Nash-playing individuals relative to a first-best solution. The combination of a public goods aspect inducing too little and a contest aspect inducing excessive incentives for private provision of this good is the key point of this paper. The benefit of these theories' contrasting predictions is that we are able to construct versions of our model where each effect is greater or lesser in magnitude we can then assess how the gap between privately and socially optimal levels of provision changes. By doing so we can explore the extent to which we find ourselves disparate from the socially efficient solution

Whilst modelling this motivating example is in itself interesting, it also generates first insights into a much more general setting where aspects of public good provision and contests interact. Examples of these include eco-tourism and environmental volunteering.

In this paper, we shall not only study bird feeding as an interesting environmental economic phenomenon in its own right, but also its ability to represent these alternative cases. In particular, it is the contest between neighbours that drive their feeding decisions and thus provide the stimulus for the role of a mixed public good in delivering voluntary contributions which would otherwise not materialise. The competitive mechanism through which this occurs is pivotal here, and requires great scrutiny when assessing the transferability of this case to other situations both within and outside of the environmental economics arena.

In the UK, bird feeding is a common and well-practiced act. Studies (Davies et al; 2009, Saggese et al; 2011) estimate that as many as 48% of the population at least occasionally feed birds. Furthermore, 87% of people in the UK have private access to a garden, with a significant proportion engaging in a range of 'wildlife gardening' techniques to enhance biodiversity within their local environment. The manufacture of seed for supplementary feeding also constitutes a noteworthy industry, with UK residents estimated to purchase around 60,000 tonnes of seed, creating a bird-food market valued at around £200 million in 2009. This illustrates an economic importance to an industry which is not only substantial in its current state, but is expanding at an estimated 4% annually (Fuller et al; 2008).

It is at this stage necessary to consider the extent to which bird-feeding holds economic, ecological and social importance. We initially consider the human benefits that accrue from this association with local wildlife. Engagement with the natural world exhibits many of the qualities which have been identified as beneficial to lasting life satisfaction by the literature on Subjective Wellbeing (SWB). 'Interconnectedness' is a good example of this, and is an emotion common to many of the SWB enhancing actions such as involvement with religion (Frey & Stutzer; 2010), community (Dutcher et al; 2007) and wider society. Furthermore, the repetition associated with 'everyday wildlife' interactions can induce positive feelings of responsibility (Jacobssen et al; 2008), routine (Diener & Biswas-Diener; 2008)) and achievement of success under uncertainty (Dolan et al; 2008). Given the many of these attributes that bird-feeding complies with (see Fuller et al (2008) for an overview), it appears highly relevant to explore the main factors determining if and to what extent individuals' decide to feed birds in their own garden. Given that such activities can induce positive feelings of social responsibility and connectivity, this may suggest that there are wider social benefits to understanding the factors which drive people to engage with their local environment. Socially beneficial examples could relate to improving the quality of life for elderly members of society (Rappe; 2005), providing children with an extended level of education (Louv; 2008) or allowing people to recover more quickly from serious health issues (De Vries et al; 2003).

Even if feeding birds is beneficial to humans, it may be deemed unjustifiable if substantial evidence exists to suggest it is detrimental to birds. Arguments against the act surround notions of species over-dependency (Sagesse et al; 2011), improper nutrition for

juvenile birds (www.rspca.org.uk) and the ecosystem-related consequences of artificially elevated populations (Cannon et al; 2005). Current advice attempts to combat many of these objections by providing more detailed advice of when supplementary feeding is and is not conducive with the welfare of birds (see www.rspb.org.uk for one such source).

There is growing evidence that an ecological importance exists to supplementary feeding, yet the nature of this aid is quite complex. This is because the help offered from artificial food would seemingly take two differing roles simultaneously. Firstly, Fuller and co-authors (2008) explain that feeding birds in UK cities enables avian populations to viably thrive within the urban environment. Whilst not explicitly defined in their paper, we assume that 'urban-adapted species' describe those which can settle permanently within the confines of non-rural landscapes. Secondly, bird-feeding may prove ecologically necessary through the benefits it yields as an 'emergency stock of food'. Longitudinal studies consistently show a greater tendency of birds to visit urban bird tables in times of harsh weather conditions (Glue; 2006). Such species would normally reside in woodland or farmland habitats and one potential explanation for this ever more prevalent encroachment may relate to habitat loss and/or changes in agricultural practices which have occurred within the UK and other developed nations.

The role of bird feeding to either sustain resident species, or as an emergency fund for migratory or transient birds to 'dip into' illustrate the potential importance of supplementary feeding to sustain or even enhance biodiversity. This may also explain the urge of environmental organisations to issue their aforementioned detailed guidance.

It is also highly relevant and insightful that these avian benefits align so neatly with those which accrue to humans from bird-feeding. Firstly, the two streams of benefit complement one another in the aspects of human utility enhancement they appear to fulfil; the sustaining of 'urban adapted species' ensures an interaction and engagement with local wildlife which is repeated and interconnected, whilst the emergency stocks facet of bird feeding enhances human welfare from a dependency and uncertainty of outcomes standpoint. Furthermore, the latter of these sources ensures that this pro-social activity is self-supporting. Humans will increase their instances of feeding in winter time, when feeding is most productive in attracting different types of birds to their gardens, thus enabling them to feel a greater sense of responsibility. Simultaneously, this is the exact time of year when the emergency stocks are most necessary, and so the greatest variety of species will profit accordingly.

So far, we have introduced the act of bird feeding among local neighbourhoods as a motivating example to understand why the private contributions to a public natural resource can exceed the level predicted by pure public goods theory. This occurs through a combination of the impurity surrounding the contribution action, the contest which ensues between neighbours and the freedom of the 'consumer good' to arrange themselves in proportion of food densities. Whilst this is interesting theoretically, it appears that there

may be important ecological and socio-economic reasons to explore this topic more thoroughly, with increasing evidence that both humans and birds benefit from the act of supplementary feeding in local urban environments. Furthermore, grasping a more rigorous understanding of the role of private motivations in determining contributions to public goods may prove insightful for a range of other policy arenas. This applies to the field of environmental economics and toward wider social and economic situations where extracting private funds currently fails to fully exploit the true willingness of its beneficiaries to support and supply a good.

## The Model

### *The Special Case*

To introduce the world we are modelling, we shall begin by outlining a special, simplified case of our neighbourhood. Here we make a number of simplifying assumptions, some of which shall later be relaxed. Firstly, we assume our neighbourhood population to be homogenous, and thus impose identical incomes, tastes and preferences across individuals. We also restrict ourselves to a single bird species, whose members arrange themselves between gardens in accordance with Ideal Free Distribution theory. This implies that birds are highly mobile within our neighbourhood. Furthermore, the number of birds (N) is fixed, meaning the bird population is independent of the aggregated food stocks. Introducing this variable as an exogenous parameter is not only useful for model simplification purposes, but also allows us to assess the Nash equilibrium against the first best when only the contest but not the public good effect is present. Under such circumstances, we can confidently predict that instances of over-provision should occur.

In this special version of the model, no one neighbour is influential enough to impact upon the cost of attracting a bird, which then remains constant for any feeding decision of a neighbour. We shall see later that this accentuates the contest element and shares intuition with the price-taking behaviour of agents in perfectly competitive markets. Such a scenario would be realisable where we have a 'large neighbourhood'. The interpretation of this which most naturally resonates is a settlement with a large or concentrated number of human residents ($M$). However, an equally feasible notion of a large neighbourhood is one where the bird species is far ranging in its feeding habits. For example, 'flock birds' such as Starlings will travel great distances in search of food. Hence, a far larger number of neighbours actually compete when attempting to attract this type of bird. By contrast, a less nomadic bird, such as a Blue Tit or Robin, will concentrate their feeding in a small geographical area, constituting a 'small neighbourhood'.

### *The Nash Equilibrium*

Once we have defined its structure, we shall initially derive the Nash equilibrium of this simple model. We will then compute the level of effort which is optimal socially, thus

enabling us to see if these two levels differ, and, if so, whether this is in an over-dissipating direction. We use a Cobb-Douglas function to represent the utility of a given neighbour. Equation (1) shows that neighbours can derive utility ($U_i$) either from birds which visit their garden ($n_i$) or through the consumption of other goods ($x_i$):

$$U_i = x_i^{(1-\alpha)} n_i^{\alpha} \qquad (1)$$

Given the small element of one's budget that is empirically assigned to bird feeding, we assume α to be positive yet fairly close to zero. Any individual is of course constrained by a budget ($Y$), denoted through (2). The term $s_i$ is the quantity of bird seed bought and dispensed in a neighbour's garden. Each neighbour purchases this at price ($p$) in order to attract birds to their garden.

$$Y = x_i + ps_i \qquad (2)$$

Note that we normalise the price of other goods ($x_i$) to unity. In order to ensure that our utility function and budget constraint are expressed as functions of the same variables, we will have to appreciate the way in which $n$ is derived from $s$. Expression (3) relays this mechanism, with $s$ here denoting the seed dispensed by one representative neighbour:

$$n_i = \frac{s_i}{\sum_{j=1\ldots M}^{j} s_j + Q} . N \qquad (3)$$

The above formula supposes that the number of birds coming to any one neighbour's garden will depend upon the seed allotted by that neighbour in relation to the total food stocks contained within the neighbourhood. These stocks include both the aggregated seed of all neighbours ($\sum s_j$ in (3)) and exogenous natural food stocks which occur within the neighbourhood ($Q$). This fraction is multiplied by the number of birds which are present in the neighbourhood (N). Expression (3) describes a Tullock-style contest (Tullock, 1980), and resembles the behaviour of foraging birds as dictated by the Ideal Free Distribution theory.

A crucial simplifying assumption within this first version of our model is that the stocks of feed dispensed by all other households ($[M-1]s_j$) or the natural food stock ($Q$) is sufficiently large that an individual's feeding efforts have a negligible effect on the total amount of food provided. Hence, each neighbour takes $n$ as a linear function of $s$. Under these conditions, we are permitted to use Equation (3) to amend our expression in (1). We construct our associated Lagrangian Function ($L$) via Equation (4):

$$L = x_i^{(1-\alpha)} s_i \left[\frac{N}{\sum_{j=1\ldots M}^{j} s_j + Q}\right]^{\alpha} + \lambda(Y_i - x_i - ps_i) \qquad (4)$$

Taking the first order conditions and imposing symmetry ($\bar{s} = s$), we can then solve for these expressions:

$$\frac{dL}{dx_i}: \quad (1-\alpha)\, x_i^{-\alpha} s_i \left[\frac{N}{\sum s+Q}\right]^{\alpha} = \lambda \qquad (5(i))$$

$$\frac{dL}{ds_i}: \quad \alpha \left[\frac{N}{\sum s+Q}\right] x_i^{(1-\alpha)} s_i^{(\alpha-1)} = p\,\lambda \qquad (5(ii))$$

Substituting 5(i) into 5(ii) and cancelling yields:

$$\alpha x_i + \alpha p s_i = p s_i \qquad (6)$$

It is noteworthy that the above expression is independent of $N$, meaning that the exact threshold of the bird population is a not crucial for the individual when they form their equilibrium effort. We make one small adjustment in that we express (6) in the form of income ($Y$) denoted in (2) and rearrange to find the Nash equilibrium level of seed purchases:

$$s^* = \frac{\alpha Y}{p} \qquad (7)$$

Equation (7) gives the standard Cobb-Douglas result. The individual maximises their utility at a seed dispensation level ($s^*$) which is a product of their taste for birds (α) and their income ($Y$), divided by the price of the good ($p$) itself. Simple comparative statics are intuitive; seed purchase increases with a rise in income or taste and decreases with a rise in the commodity's price. Note that this equilibrium is independent both of the number ($M$) and feeding thresholds ($s_j$) of other neighbours. This confirms that whilst we impose symmetry in this model, yet can make the distinction between $s_i$ and $s_j$ if need be, this is not crucial to our analyses in this limiting case.

*The Socially Optimal Level*

The first-best allocation can be found by equating the Marginal Social Cost (MSC) to the Marginal Social Value (MSV) of bird feeding. We consider an appropriate definition for the MSC as the monetary cost to society of attracting one more bird to gardens. Again we impose symmetry (meaning $s_i = s_j$) and now capture aggregate artificial feeding through the expression $Ms$. To discover the MSC, we use this updated version describing the Tullock Contest in Equation (3(i))

$$n = \frac{s}{Ms+Q}.N \qquad (3(i))$$

By differentiating this term with respect to $s$, we establish how the number of birds alter with a unit change in seed dispensed:

$$\frac{dn}{ds} = \frac{QN}{(Ms+Q)^2} \qquad (8)$$

We now wish to find the reciprocal of (8), as this will illustrate the change in seed required to entice one extra bird to gardens:

$$\frac{ds}{dn} = \frac{(Ms + Q)^2}{QN} \qquad (9)$$

We now multiply (9) by the price of seed ($p$) to obtain the MSC. This gives a monetary measure of the cost involved in attracting one extra bird into the gardens of neighbours:

$$\text{MSC} = \frac{p(Ms + Q)^2}{QN} \qquad (10)$$

Having derived an expression for the Marginal Social Cost, we must now define and then produce a term to represent the Marginal Social Value (MSV) of birds. The MSV should indicate the monetary value which an individual associates with the benefit of enticing one extra bird to their garden. Using our model, this can be expressed as the Marginal Rate of Substitution between our two consumption goods, $x$ and $n$:

$$MSV = -\frac{\partial x}{\partial n}\Big|_{U\ Constant} \qquad (11)$$

A relatively simple way of calculating (11) is to use a version of the chain rule below:

$$\frac{\partial x}{\partial n}\Big|_{U\ Constant} = \frac{\partial x}{\partial U} \times \frac{\partial U}{\partial n}$$

These two constituent parts of this equation can be established directly from our utility function (1):

$$u = x^{(1-\alpha)} n^{\alpha}$$

$$\frac{dU}{dn} = \alpha\, x^{(1-\alpha)} n^{(\alpha-1)} \qquad (12(i))$$

$$\frac{dU}{dx}: \quad (1-\alpha)\, x^{-\alpha} n^{\alpha}$$

$$\frac{dx}{dU} = \frac{1}{(1-\alpha)}\, x^{\alpha} n^{-\alpha} \qquad (12(ii))$$

Using 12(i) and 12(ii), we can now derive $\frac{dx}{dn}$:

$$\frac{dx}{dn} = \frac{\alpha}{(1-\alpha)}\left(\frac{x}{n}\right) \qquad (13)$$

We can then use (3) to remove n from Equation (13), and express this in terms of s. The notation $s^F$ conveys the fact that this is the effort level of a representative neighbour seen as optimal from a first-best perspective:

$$\frac{dx}{dn} = \frac{\alpha}{(1-\alpha)}\left(\frac{x\,(Ms+Q)}{sN}\right) \qquad (14)$$

Equating MSC (10) and MSV (14), substituting in (2) and rearranging to make the expression comparable to (7) yields,

$$s^F = \frac{\alpha Y}{p}\left(\frac{Q}{(1-\alpha)s^F + Q}\right) \qquad (15)$$

Comparing (7) with (15), we conclude that the first-best level of seed an individual should allot ($s^F$) lies below that which the individual would choose ($s^*$). Thus, we confirm that there is an over-exertion of effort when decisions are left to neighbours to select their optimal feeding level. Recall that this model currently lacks a public goods aspect as the bird population (N) is exogenous and so our only distortion is the contest effect. Consequently, the elevated Nash equilibrium represents the superfluous individual action driven through competitive motivations.

This initial model contains many simplifying assumptions which may cause a disassociation with the empirics of bird feeding at this point. However, it serves as a helpful starting point from which to begin our analyses. Furthermore, it establishes a useful reference point that helps to identify the key drivers behind the results which follow.

*The Exogenous Population Model*

In reality the number of individuals interacting across a neighbourhood through a bird-feeding contest will be finite, sometimes even quite small. We therefore proceed by relaxing the assumption of a large neighbourhood used in the special case, appreciating that neighbourhoods vary in size and that such differences may have a bearing upon the effort decisions of individuals. Studies have assessed the role of effort exertions both within (Baik; 2008) and between (Nitzan & Ueda; 2009) groups of varying sizes, and have discovered that the implications of varying such a parameter are often complex and context-dependent (see (Konrad; 2009) for an overview). Our model does holds the potential to reinforce or refute these ideas, although our greater focus is to assess what additional role an offsetting public goods effect may hold.

As previously described, neighbourhood size can instead be characterised through avian behaviour, and by analysing size through this method, our model hopes to build upon

the findings of Cressman et al (2004). This study assesses how relative mobility influences the feeding distribution of birds, and we complement this work by showing how *human* decisions may change for birds whose biology or habit lead them to more localised foraging tendencies. We retain the assumptions of species and neighbour homogeneity, and also that of an exogenous bird population, supressing a public goods aspect.

*Nash Equilibrium*

We adjust Equation (3) to account for the fact that any given neighbour will have to respond to the exogenous decisions of other residents. Expression (3a) helps with this, decomposing the denominator in (3) to separate out $s_i$, the seed allotment decision of the individual, from $s_j$, the seed investments of any other neighbour, which can be aggregated across all other feeders ($[M-1]s_j$). This decomposition allows us to disentangle the various feeding locations and show those which the individual can perceive as exogenous.

$$n_i = \frac{s_i}{s_i+[M-1]s_j+Q}.N \qquad (3a)$$

However, with a finite neighbourhood size we can no longer assume that the individual perceives $n$ as a constant linear function of $s$. The easiest way to achieve expressing our utility function and budget constraint through the same variables is to replace $n_i$ in the utility function with the right hand side of (3a). This creates 16(i). We can then re-write our Lagrangian function (16(ii)) expressed purely in terms of $s_i$ and $x_i$:

$$U_i = x_i^{(1-\alpha)}\left(\frac{s_i N}{s_i+[M-1]s_j+Q}\right)^{\alpha} \qquad (16(i))$$

$$L = x_i^{(1-\alpha)}\left(\frac{s_i N}{s_i+[M-1]s_j+Q}\right)^{\alpha} + \lambda(Y_i - x_i - ps_i) \qquad (16(ii))$$

We again calculate First Order Conditions and then impose symmetry to find $s$:

$$\frac{dL}{dx_i}: \quad (1-\alpha)\, x_i^{-\alpha}\left[\frac{s_i N}{s_i+[M-1]s_j+Q}\right]^{\alpha} = \lambda \qquad (17(i))$$

$$\frac{dL}{ds_i}: \quad \alpha\left[\frac{([M-1]s_j+Q)N}{(s_i+[M-1]s_j+Q)^2}\right] x_i^{(1-\alpha)}\left[\frac{s_i N}{s_i+[M-1]s_j+Q}\right]^{(\alpha-1)} = p\,\lambda \qquad (17(ii))$$

We use the same methodology of the proceeding section to then derive the new Nash Equilibrium:

$$s^* = \frac{\alpha Y}{p}\left[\frac{[M-1]s+Q}{(1-\alpha)s^* + [M-1]s+Q}\right] \qquad (18)$$

The term contained in the square brackets of (18) is strictly less than one. Therefore, when comparing this new Nash equilibrium to that of the special case (7), the result is a fall

in the individual's optimal effort decision under the new conditions of a finite neighbourhood.

Equation (18) does not give a closed-form solution, and whilst it is possible to rearrange the expression so as to engineer this, for the purposes of our study a more appealing method for exploring the impact of neighbourhood size through comparative statics is to graphically demonstrate the drivers at work within this model. To achieve this, we rearrange Equation (18) so that all elements outside of the square brackets move to the left-hand side of the expression, denoted through (18(a)) below:

$$\frac{ps^*}{\alpha Y} = \frac{[M-1]s+Q}{(1-\alpha)s^* + [M-1]s+Q} \qquad (18a)$$

By making this adjustment, we are able to now present both the left-hand side and right-hand side of the above equation on the same graph (Figure 1a). We now want to consider how this Nash Equilibrium, signified by the intersection of the left (line) and right (curve) hand sides, adjusts as the neighbourhood size rises. 'Larger' neighbourhoods could refer to scenarios where artificial food stocks other than those dispensed by the individual $[M-1]s$ are large compared to $s$. Given the nature of the right-hand side term, this curve will pivot upwards as we move towards a larger neighbourhood. Figure 1b describes this movement, illustrating that $s^*$ rises as the neighbourhood gets larger. A further note is that, due to the curvature of the line, these incremental increases in $s^*$ slow for a given rise in $[M-1]s$. As we move toward an infinitely large neighbourhood, we converge towards point E. This is the value of $s^*$ which we discovered in our special case, and holds a value of $\frac{\alpha Y}{p}$.

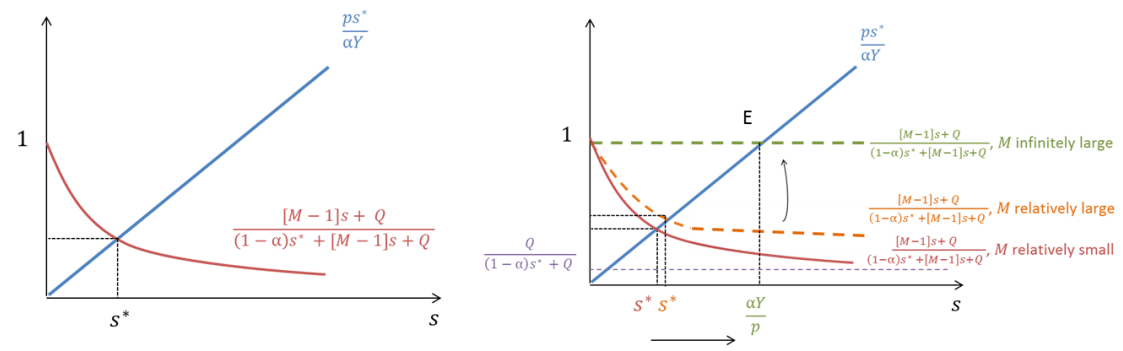



**Figure 1a:**
An Implicit Analysis of the Static Nash Equilibrium

**Figure 1b:**
The Impact of a Rising Neighbourhood Size.

It is possible to interpret this adjustment intuitively. As a neighbourhood contains fewer and fewer rival residents the contest is dampened. Thus, there is a smaller impetus

for those remaining neighbours to fight so fiercely in their attempts to draw birds to their private garden and away from those nearby. We could assess this in the limit by imagining a 'one person neighbourhood'. Here, the contest element collapses, with the now monopolistic individual knowing that any level of seed put out for birds will result in a strong redistribution of birds toward their garden. This effect is exacerbated further in a case where the monopolistic feeder lives in a neighbourhood devoid of natural food ($Q$). We can check for consistency with (7) by assessing how (18) adjusts if our neighbourhood returns to its infinitely large level. In this case, the additional expression in the denominator of our bracketed term ($(1-\alpha)s^*$) becomes less and less influential, meaning $s^*$ tends to the special case.

This implicit analysis could also be used to demonstrate the impact upon the Nash equilibrium of a neighbourhood having varying levels of natural food ($Q$). Figures 1c and 1d confirm that the effects are very similar, with the only difference being the threshold of convergence upon which the individual tends towards as $Q$ falls. As before, when natural food stocks become very large, the right-hand side tends to one for all values of $s$ and we return to the Nash Equilibrium of the Special Case where the individual is non-influential and dispenses at a value of $\frac{\alpha Y}{p}$. As $Q$ falls, the competitive influences decreases in our neighbourhood and the individual holds a lowered incentive to dispense seed so intensely in order to procure birds to their garden. This effect is captured by the downward swivelling of the right-hand side and a fall in the intersection which derives $s^*$.

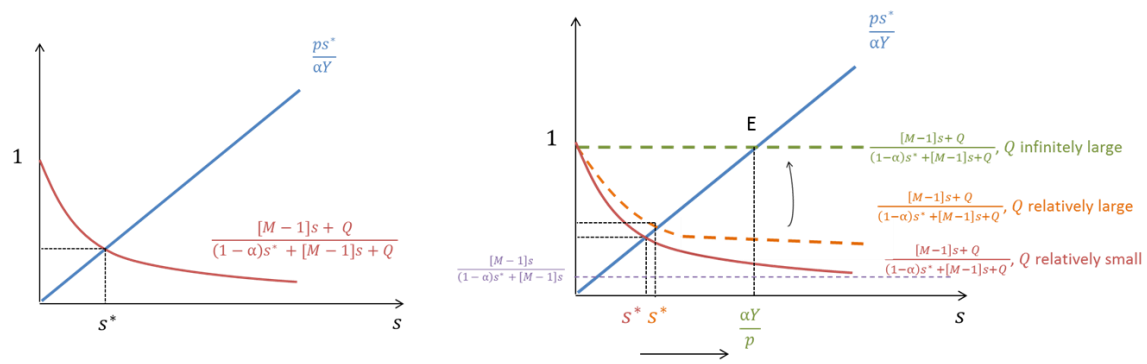



**Figure 1c:**
An Implicit Analysis of the Static Nash Equilibrium

**Figure 1d:**
The Impact of a Rising Natural Food on the Nash Equilibrium

There is an empirical ecological importance in discussing a change in $Q$ in addition to but separately from $[M-1]s$. This is that we can assess how the effort decision of our individuals adjusts across potential habitats. For example, in remote rural settings, we are likely to have a low level of $[M-1]s$, as there are relatively few competing residents, but this might be offset by a high level of natural food which a neighbour must contest with in order to attract birds to their garden. By contrast, $Q$ is likely to be fairly low, even non-

existent, in densely-populated urban areas, but here the concentration of other human feeders will be higher, meaning $[M-1]s$ is the main source of competition for a given neighbour. It is also credible to envisage habitats where both $Q$ and $[M-1]s$ are either low or high, and so it is prudent to investigate how our equilibrium changes when each of these variables are adjusted in isolation.

Returning to the basic comparative static results, $s^*$ retains a positive and negative linear relationship with income and price respectively. With its additional (yet relatively minor) inclusion in the denominator of (19), there is a slight adjustment in the way $s^*$ alters with changes in tastes (α). However, simulations of a closed-form solution confirm that a positive and broadly linear relationship is maintained between these two variables. Our new comparative static result can be introduced, assessing the way in which $s^*$ changes with alterations in other food sources, be this from a greater population of neighbours ($[M-1]s$), or from natural sources ($Q$). This association is confirmed as positive yet concave, pertaining to the two facts examined in Figures 1a to 1d. The positive relationship is derived from the contest element of our model, forcing any neighbour to compete more intensively in the presence of a greater number of alternative feeding sources. The concavity, played out as a function of Cobb-Douglas Model, relates to the increasing futility of such effort as the number of rival sources tends to infinity. Of course, the threshold upon which this concave expression converges is that of the Special Case (7).

*The Social Equilibrium*

It is not possible to say whether the lower Nash investment decision of 'small neighbourhoods' is better or worse than in the special case until we have determined if the first-best feeding rate is affected by this change in conditions. The original social optimum, defined by (15), is re-written below:

$$s^F = \frac{\alpha Y}{p}\left(\frac{Q}{(1-\alpha)Ms^F + Q}\right) \qquad (15)$$

Recall that we did not rely upon an infinite neighbourhood size when deriving this and therefore the expression for the social equilibrium is then applicable to all neighbourhood sizes and remains unchanged for this version of our model.

Again we can use graphical analysis to see how the social equilibrium adjusts with neighbourhood size. We again begin by rearranging the expression to give a linear left-hand side and curved right-hand side:

$$\frac{ps^F}{\alpha Y} = \frac{Q}{(1-\alpha)Ms^F + Q} \qquad (15a)$$

Replicating the steps then taken for the Nash solution, we can confer a relationship through Figure 2b, which symbolises how the two sides adjust as the value of $[M-1]s$ rises. This creates a downward swivel in the curve and thus from the perspective of a first-

best solution, it would be better if each individual fed less intensely in a larger neighbourhood *ceteris paribus*.

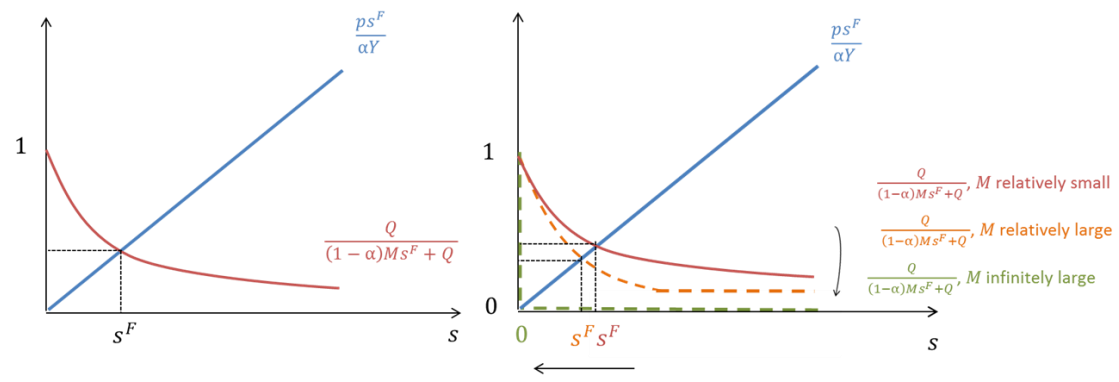
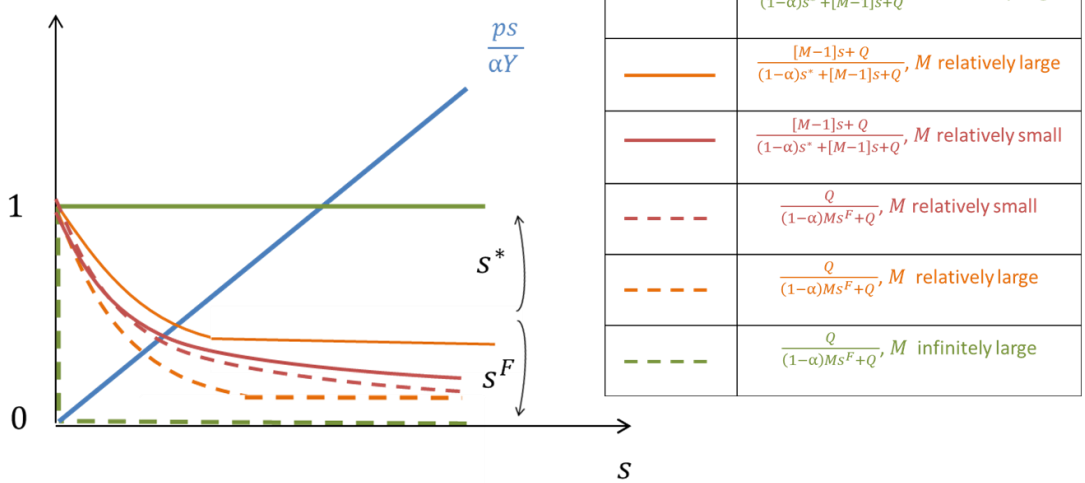



**Figure 2a:**
An Implicit Analysis of the Static Social Equilibrium

**Figure 2b:**
The Impact of a Rising Neighbourhood Size.

The beauty of such an analysis is that we can present the two above equilibrium results (1b and 2b) on the same diagram. Figure 3 captures this, illustrating the divergence of the Nash and first- best solutions as the number of rival neighbours rise.




| Line | Equation |
|---|---|
| | $\frac{[M-1]s+Q}{(1-\alpha)s^*+[M-1]s+Q}$, $M$ infinitely large |
| | $\frac{[M-1]s+Q}{(1-\alpha)s^*+[M-1]s+Q}$, $M$ relatively large |
| | $\frac{[M-1]s+Q}{(1-\alpha)s^*+[M-1]s+Q}$, $M$ relatively small |
| | $\frac{Q}{(1-\alpha)Ms^F+Q}$, $M$ relatively small |
| | $\frac{Q}{(1-\alpha)Ms^F+Q}$, $M$ relatively large |
| | $\frac{Q}{(1-\alpha)Ms^F+Q}$, $M$ infinitely large |

**Figure 3:**
An Implicit Analysis of the divergence from social efficiency as the neighbourhood size rises.

Our conclusion for the special case was that we witnessed an over-exertion of feeding effort by neighbours. With no alterations in the expression for first-best optimum and yet seeing our new individual equilibrium (18) fall, our model predicts a convergence toward social efficiency as we reduce neighbourhood size. From an inspection of the alterations in the bracketed terms of expressions (15) and (18), it becomes clear that when 0

$< \propto < 1$ over-provision persists within the model and that this over-dissipation of effort rises as $[M-1]s$ increases. This is reinforced by Figure 3, where the Nash equilibrium always appears above that of the first-best solution, and we witness a greater gap between dashed and filled lines as the neighbourhood size rises.

If we instead explore the impact of increasing the stock of natural food on the first-best solution, this direction of efficiency is not so clear. Using the same analysis as above, we see that the social optimum also shifts upwards towards our special case (seen in Figure 2d). Thus, the analysis of Figure 3 no longer holds, as now $s^*$ and $s^F$ both move in the same direction. In the limiting case of an exceptionally large level of $Q$, the Nash and first-best solutions converge to a value of $\frac{\alpha Y}{p}$ :

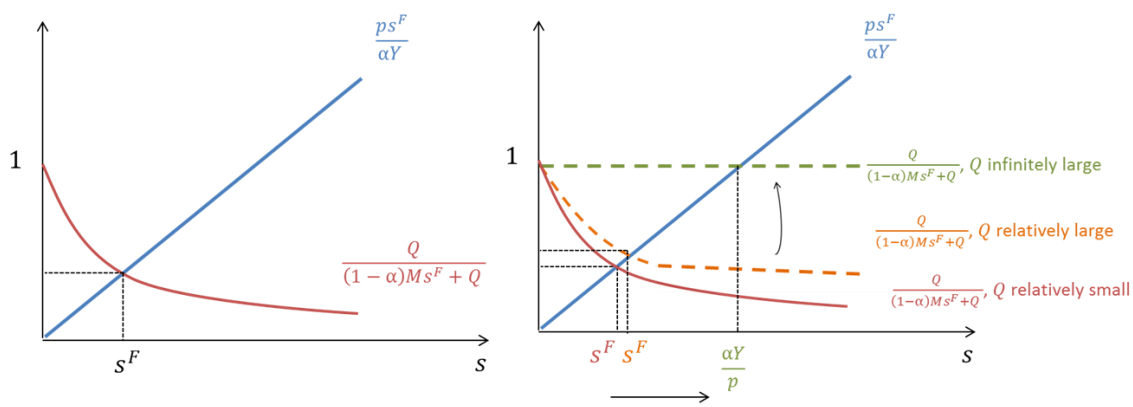



**Figure 2c:**
An Implicit Analysis of the Static Social Equilibrium

**Figure 2d:**
The Impact of a Rising Natural Food on the first-best solution.

How can we associate this difference with the Contest elements within our model? In the former case, where we increase the number of other supplementary feeders, our individual feeds more intensively, but a social planner would prefer them to relent from feeding. In this scenario, the reason for the divergence is that whilst the individual feeds in order to try and attract more birds to their garden, they disregard the negative implications that this has on the neighbours who they 'steal' birds from. However, from the first-best standpoint this disutility of stolen birds has to be accounted for. In essence, this reallocation of birds from one neighbours' garden to another constitutes wasteful duplication of effort as a social planner is indifferent which neighbour receives the birds so long as they appear in the garden of a neighbour.

In the latter case, we are adjusting the natural food holding all other variables constant. Here, the individual is feeding in greater quantities for the same purposes, only this time their 'rival' is that of the natural sustenance as opposed to other artificial feeders. However, this explains why the first-best solution also advocates an intensification of feeding. Now, a greater effort from a neighbour will predominantly result in a relocation of

birds from natural sources, where society yields no utility, to neighbours' gardens, where they do. Because the contest is not occurring between two neighbours, there is no wasteful duplication of effort and the motives of the individual and the social planner align.

From a policy perspective, our analysis concludes that a 'small neighbourhood' leads to a lower but more socially optimal level of effort when decisions are purely driven by an inter-neighbour contest. The rationale behind this is clear: in smaller neighbourhoods the negative spillovers are lessened as they affect fewer people and hence the wedge between the private and the social optima is smaller. This resonates with the empirical notion that close-knit or localised communities expend effort in a more efficient manner (Frank; 2003). If we instead use our avian interpretation of neighbourhood size, our results indicate that regions which contain a greater proportion of bird species who forage locally create a more economically and ecologically efficient neighbourhood than ones which contain a higher percentage of birds with nomadic feeding tendencies. This is because in the latter case, the birds are essentially living in a 'neighbourhood' with a greater number of competing neighbours ($[M-1]s$ ) *ceteris paribus*.

*The Endogenous Population Model*

The existence of over-provision in the models discussed until is unsurprising given that we still only include one of our two contrasting effects. Neither model representing an exogenous bird population gives an individual the opportunity to contribute to a public good and therefore no incentive to refrain from exerting effort in behaviour akin to free-riding. With just contest-induced motives active thus far, a situation describing autonomous over-investment is a natural product of our world in its current form. The next challenge is to remove the assumption that bird populations are exogenous and repeat our analyses when both public good and contest effects exist within our model. Ideal Free Distribution Theory implies that a neighbourhood which feeds relatively intensively and therefore has a greater concentration of local sustenance compared with adjacent regions would profit from elevated local bird populations. This could occur in one of two ways; either through the migration of new birds into this now food-rich location and away from other neighbourhoods, or through the additional reproductive success which will be afforded from birds living in a now more nutritious environment. The motivations for this amendment are obvious as we finally allow our model to assess the impact of including the public good aspect, identifying the impact that avian population adjustment has on human decision-making.

In order to capture the opportunity for avian population adjustment, we replace N in our model with an expression where bird numbers react positively to food levels. How a public good is introduced into a model can have profound implications for the level of ensuing contributions (Isaac & Walker; 1988, Chan et al; 1996, 1999) and so it is important to use a mechanism which is credible and realistic. One method of doing this is contained in (19) below, which replaces (3a) and gives a new expression to resemble our contest:

$$n_i = \frac{s_i(s_i+[M-1]s_j+Q)^{\beta}}{s_i+[M-1]s_j+Q}, \quad \beta \geq 0 \qquad (19)$$

As well as allowing us to incorporate a public goods aspect into our model, transforming (3a) into (19) affords us the opportunity to evaluate how different values of β influence our equilibrium solutions. This parameter can be thought of as the degree to which higher food stocks provide more birds, analogous to returns to scale. Through the following calculations, we use this new endogenous population expression whilst also retaining a relaxation of the assumption that there exists a finite population of neighbours.

*Nash Equilibrium*

In order to calculate the new Nash solution, we apply the same method from the 'exogenous population' model, simply amending the initial utility function to appreciate the new public goods opportunity:

$$U_i = x_i^{(1-\alpha)} \left(\frac{s_i(s_i+[M-1]s_j+Q)^{\beta}}{s_i+[M-1]s_j+Q}\right)^{\alpha} \qquad (20(i))$$

$$L = x_i^{(1-\alpha)} \left(\frac{s_i(s_i+[M-1]s_j+Q)^{\beta}}{s_i+[M-1]s_j+Q}\right)^{\alpha} + \lambda(Y - x_i - ps_i) \qquad (20(ii))$$

$$\frac{dL}{dx_i}: \quad (1-\alpha)\, x_i^{-\alpha} \left[\frac{s_i(s_i+[M-1]s_j+Q)^{\beta}}{s_i+[M-1]s_j+Q}\right]^{\alpha} = \lambda \qquad (21(i))$$

$$\frac{dL}{ds_i}: \quad \alpha \left[\frac{(s_i+[M-1]s_j+Q)^{\beta}[\beta s_i+[M-1]s_j+Q]}{(s_i+[M-1]s_j+Q)^2}\right] x_i^{(1-\alpha)} \left[\frac{s(s+[M-1]\bar{s}+Q)^{\beta}}{s+[M-1]\bar{s}+Q}\right]^{(\alpha-1)} = p\,\lambda \qquad (21(ii))$$

Imposing symmetry and rearranging the above expression yields our associated Nash equilibrium effort level:

$$s^* = \frac{\alpha Y}{p}\left[\frac{\beta s+[M-1]s+Q}{(1-\alpha(1-\beta)s^*+[M-1]s+Q}\right] \qquad (22)$$

The introduction of a public good leads to some interesting changes within the individually-optimal feeding decision. Crucially, we realise that the extent to which the level of exertion coincides with its previous counterparts (7) and (18) hinges solely upon the value of β.

When β is equal to zero, we return to a world whereby bird populations are unaffected by feeding concentrations. We can confirm algebraically that the consequence of this is a partial collapse in the bracketed expression of (22), leading to a reversion to the expression for $s^*$ denoted by (18). Conversely, consider the impact of when β is equal to unity. This would represent an environment exhibiting 'constant avian returns to scale' from an associated change in the level of food made available within a neighbourhood. Here, the bracketed term in (22) collapses completely (to one) and we return to the equilibrium level of the special case (7). Figure 4 relays these insights diagrammatically:

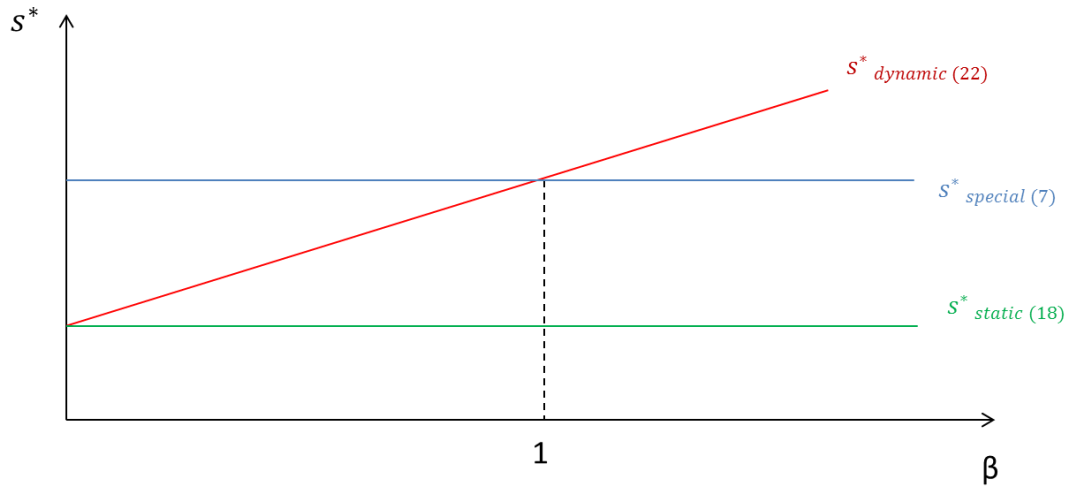



**Figure 4:**
The relationships between the various Nash Equilibrium effort levels as the productivity of feeding (β) rises.

This result illustrates that the absolute level of feeding in the presence of a public good element is completely dictated through the degree of productivity associated with pro-social activity. This analysis suggests that the greater the value of β, and thus the more easily attainable the public good, the greater the absolute level of effort exerted by the individual. We must realise that witnessing a higher value of β simply represents the enablement of a greater level of birds ($n_i$) to be achieved by an individual at any given food level. As we assume birds to be a normal good, this increased effort can be taken to represent an outward swinging of the budget constraint as aggregate food stocks ($Ms + Q$) increase.

To see whether the inclusion of this public good has driven any real change in the level of social efficiency requires a re-calculation of $s^F$. This should also allow us to ascertain whether, and if so to what extent, free-riding tendencies emerge.

A re-calculation of MSC and MSV is necessary given that both elements adjust under these new conditions. However, the mechanism by which these are derived does not alter, meaning we simply repeat the earlier methodology:

$$\frac{dn}{ds} = \frac{(s+[M-1]s+Q)^{\beta}[\beta Ms+Q]}{(s+[M-1]s+Q)^2}$$

$$\frac{ds}{dn} = \frac{(s+[M-1]s+Q)^2}{(s+[M-1]s+Q)^{\beta}[\beta Ms+Q]}$$

Again, we multiply the above expression by seed price in order to formulate the MSC:

$$\text{MSC} = \frac{p(s+[M-1]s+Q)^2}{(s+[M-1]s+Q)^{\beta}[\beta s+Q]} \tag{23}$$

$$MSV = -\frac{\partial x}{\partial n}\Big|_{U\ Constant}$$

$$\frac{\partial x}{\partial n} = \alpha\, x^{(1-\alpha)} n^{(\alpha-1)}\ x\ \frac{1}{(1-\alpha)}\ x^{\alpha}\, n^{-\alpha}$$

$$\text{MSV} = \frac{\partial x}{\partial n} = \frac{\alpha}{(1-\alpha)}\left(\frac{x}{n}\right) \tag{24}$$

This time, we use our adjusted contest expression (19) to express the Marginal Social Value in terms of $s$:

$$\text{MSV} = \frac{\partial x}{\partial n} = \frac{\alpha}{(1-\alpha)}\left(\frac{x\ (s+[M-1]s+Q)}{s(s+[M-1]s+Q)^{\beta}}\right) \tag{25}$$

Finally, we equate MSC = MSV by setting (23) equal to (25)

$$\frac{p(s+[M-1]s+Q)^2}{(s+[M-1]s+Q)^{\beta}[\beta Ms+Q]} = \frac{\alpha}{(1-\alpha)}\left(\frac{x\ (s+[M-1]s+Q)}{s(s+[M-1]s+Q)^{\beta}}\right)$$

$$s^F = \frac{\alpha Y}{p}\left(\frac{\beta Ms^F+Q}{(1-\alpha(1-\beta))Ms^F+Q}\right) \tag{26}$$

Having ascertained a new first-best equilibrium, we initially compare this with the original optimum (15), before considering whether these adjustments create any differences between lesser private effort exertion and that deemed communally best.

When moving from $s^F$ of the exogenous population model (16) to the endogenous population model (29), it is apparent that the socially optimal level of bird feeding is larger in the latter. To confirm this, consider the alterations that occur in the bracketed terms. Both the numerator and denominator have an additional term ($\beta Ms$), although the latter is multiplied by alpha. Given the nature of the fraction, we must observe an increase in feeding so long as $0 < \propto < 1$. If both $s^*$ and $s^F$ are now increasing, this reinforces the earlier warning that a rising individual optimum does not necessarily signal a violation of the free-rider problem.

When assessing how the new social optimum (26) relates to that of the Nash effort level (22), we can use the same analysis, this time comparing the alterations which occur in the numerator and denominator as we move from the social to private equilibrium level. The numerator rises by a factor of $(1-\beta)[M-1]s$, and again the corresponding adjustment to the denominator is this expression multiplied by α. Our assumption on the magnitudes of alpha and beta are now both critical in determining our interpretation of whether the individual over, under or exactly provides food relative to the first-best advocacy. If we assume β < 1, meaning the public good exhibits decreasing returns to scale, then $s^F < s^*$ and thus over-provision persists within our model. However, the extent of over-provision is reduced compared to the exogenous population model.

The diminishing potency of over-exertion continues as β approaches 1, or as the public good gains in its productivity. Our analysis confirms that over-dissipation is completely nullified when β equals unity, hence if bird (re-)production exhibits constant returns to scale there will be no difference between (26) and (15). Moreover, the situation where β = 1 results in a complete collapse of the bracketed fraction (to unity) of (22) and the private and social equilibrium both exist at a magnitude of $\frac{\alpha Y}{p}$. Now, the Nash equilibrium coincides with the social optimum.

We can take the analysis one step further and imagine a world where the public good offers increasing returns to scale, or where β > 1. We see that now the social optimum (26) will be at a level higher than the privately optimal amount of bird feeding (22) and so individuals under-provide seed relative to the first-best level.

Let us explicitly assess these differing scenarios from the perspective of our two effects. For either 'exogenous population model', no public goods aspect existed, leading to an unequivocal over-provision of bird seed relative to the quantity prescribed as socially desirable. In these cases, this occurred because only one of our two 'key effects' (the contest facet) was present within the model. By adapting our world to then include the second, public goods, effect, we see our results change. When nature exhibits decreasing returns to scale in providing birds,, demonstrated through small values of β, the contest effect continues to dominate, albeit to a lesser degree. However as beta rises, the over-dissipation of effort from the contest finds itself being substantially eroded by the public goods effect. This reaches a threshold, where β = 1, when the two forces perfectly offset one another and $s^*$ represents a level of feeding which exactly corresponds to $s^F$ . When beta is allowed to surpass unity, neighbours fail to exert effort in the volumes advocated by the social optimal. Under-provision now ensues within the neighbourhood, characterising the free-rider tendencies of individuals. These neighbours can now draw private benefits from the relative productivity of others' contributions in delivering birds to the neighbourhood. Put another way, when we observe increasing avian returns to scale from aggregate food levels, people can satisfy their taste for birds by dispensing a sub-optimal quantity of seed.

It is worth noting at this stage that the adjustments that we see in the Nash and first-best solutions are more poignant within smaller neighbourhoods. In a limiting case where neighbourhoods become infinitely large, some of the comparative static results displayed here and in subsequent analyses will actually create relatively insignificant changes in the behaviour of our individual neighbours. Despite this, the analyses contained here nicely demonstrate how our two offsetting effects operate, and describe how their relative potencies determine whether the aggregated private contributions of individuals within a local community will be below, at or above that which is efficient from the communal perspective.

Further Extensions

Within both our 'exogenous' and 'endogenous' population models there are still a number of assumptions which we may wish to question and adjust in order to exhort additional realism. The next two sub-sections relax two such facets.

*I. Private Natural Food ($q$)*

Natural food ($Q$) is a sensible variable to contain within our model. It offers the opportunity to construct a hypothetical scenario whereby no neighbours feed and yet birds can thrive within the neighbourhood. Additionally, it enables the modeller to assess the impact of these natural food stocks being relatively abundant or scarce in relation to aggregate ($Ms$) or individual ($s$) supplementary seed.

Despite its relevance for the model, the current notion that natural and privately provided stocks of food are located in spatially separate areas is not realistic. Whilst natural food does exist outside of private gardens, for example in urban parks or waste grounds, it is equally true that natural sustenance is contained within the boundaries of these areas. This is perhaps even more poignant across urban landscapes, where gardens constitute a high proportion of total foraging space. Furthermore, even when they feed from natural sources, the very presence of birds in people's gardens still offers a chance to engage with nature and establish inter-connectedness, and therefore can be assumed a channel from which residents derive utility. Subsequently, we briefly consider how neighbours' dispensing efforts are influenced by converting $Q$ to a disaggregated $q$, the latter representing garden-specific natural food. Of course, from a Subjective Wellbeing standpoint, we cannot necessarily assume $q$ and $s$ as perfect substitutes, as the utility-enhancing attributes of dependency and responsibility are reduced (if not eradicated) if birds forage 'naturally'. For now, we shall ignore this disparity.

We would imagine that this conversion should reduce the incentive to actively engage in supplementary feeding. Essentially, $q$ provides neighbours with a pre-existing threshold of food and consequently the marginal productivity of dispensing food falls. Assessing this effect allows us to consider how people adjust their behaviour when a

substitutable product not only exists, but also how their decisions may vary as the degree of exclusion or ownership alters.

Whilst calculations are not explicitly included here, re-running our analyses confirm our conjectures regarding the adjustments in the Nash equilibrium which occur from converting natural food stocks from an externally to privately located variable. For both the exogenous population model and the endogenous population model with $\beta \leq 1$, the equilibrium effort level of our individuals falls. This relates to a form of 'crowding out' akin to that described by other studies (see Bergstrom et al 1986 for an example). Given the susceptibility of these models to exhibit qualities of over-provision, the effort dissuasion which is facilitated through this redistribution mechanism resembles a convergence towards the associated level of supplementary feeding deemed socially optimal. It is also worth mentioning that, for a sufficiently high level of $q$ we may find the individual completely unwilling to supply supplementary feed. Subsequently, we must restrict our analyses at these corner solutions and impose the restriction the $q$ cannot be so high that the optimal seed dispensing level is at a level below zero.

Regarding the endogenous population model, this effect becomes smaller as $\beta$ rises. Why would the inclusion of a public goods effect decrease a neighbour's disinclination to feed in the presence of $q$? When $\beta$ is strictly positive, aggregate bird numbers rise from an increase in food stocks. Holding all other things constant, neighbours are now rewarded more greatly from feeding relative to a case where bird numbers are fixed (the exogenous population model). This, at least partially, re-incentivises them to feed. Further to this point, where $\beta > 1$, the conversion to $q$ actually creates a *rise* in contributions relative to its $Q$ - counterpart, lessening the extent to which this neighbourhood would under-provide.

These findings, depicted through Figure 5, suggest that amending the characterisation of natural food stocks from a location independent to an individually allotted system creates a 'regulating' mechanism. This means that neighbours reduce their feeding efforts in an over-exerting world but will raise their efforts when private contributes are falling short of the level which is socially optimal.

Reiterating our earlier reasoning, the disinclination to feed in over-providing scenarios stem from the dampened contest effects which occurs when neighbours are endowed with an initial natural food stock. However, delivering an empirical distinction between 'natural' and 'manual' food sources is not straight-forward. For example, humans who invest in wildlife gardening indirectly expend money on substances which then constitute 'quasi-natural' sources of sustenance and which are not manually dispensed in the traditional bird-feeding manner. Despite this confounding practical facet, it is interesting and important to realise the impact that a digression such as this may have upon the private actions of an individual. This gives further reason to emphasise the importance of understanding the context-specific considerations associated with the provision of environmental public goods. Indeed, it is by appreciating these types of factor that

environmental economists will be able to advocate insightful and useful policy recommendations.

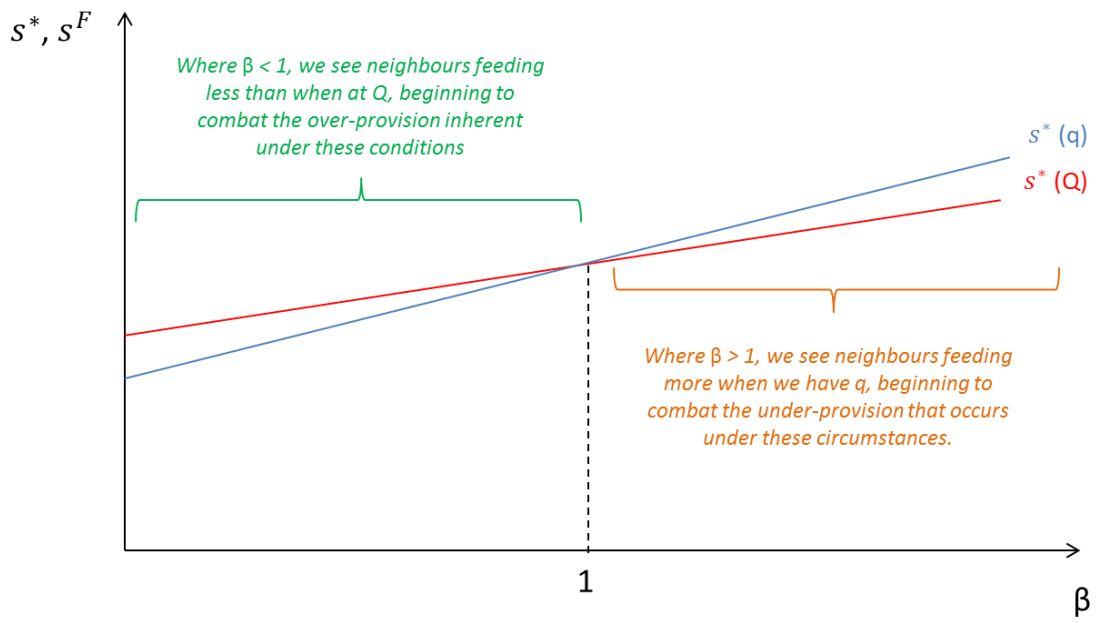



**Figure 5:**
An illustrative explanation of the moving from external to locally specific natural food.

II. *Introducing Heterogeneity in Income (Y)*

The final assumption we relax in these analyses is that which imposes symmetry across neighbours. Some degree of homogeneity is clearly realistic when examining a neighbourhood. People who live within the same residential area are likely to live in houses of similar sizes, have comparable incomes and hold some overlap in their tastes. However, strict homogeneity is unrealistic. We briefly discuss the implication of introducing dispersion in particular personal attributes upon the aggregated seed investment of a neighbourhood. The standard theoretical prediction is that 'asymmetry between contestants who participate actively in the contest reduces total expenditure' (Konrad; 2009, p.63-64). We consider one attribute, income ($Y$), here. In our opinion, this constitutes one of the most empirically intuitive aspects to model heterogeneously.

The existing literature casts a varied picture regarding the impact of disparate incomes. Some studies show that the aggregate impact is unaffected (Sugden; 1984, Buckley & Croson; 2006, Bartling & von Siemens; 2011), whilst other studies suggest that wealth or power differences can lead to greater (Chan et al; 1996, Bewley; 1999, Olszewski & Rosenthal; 2002, Frank; 2003) or lesser (Isaac & Walker; 1988, Doraszelski & Markovic;

2007) contributions. These studies assess the impact of heterogeneity in both experimental and empirical settings, applied to a range of topics including employee effort, taxation, group co-operation and advertising.

In order to assess the impact of income heterogeneity without complex comparative static analysis of a closed form solution, we instead display the solution implicitly through the graphical model of Figure 1:

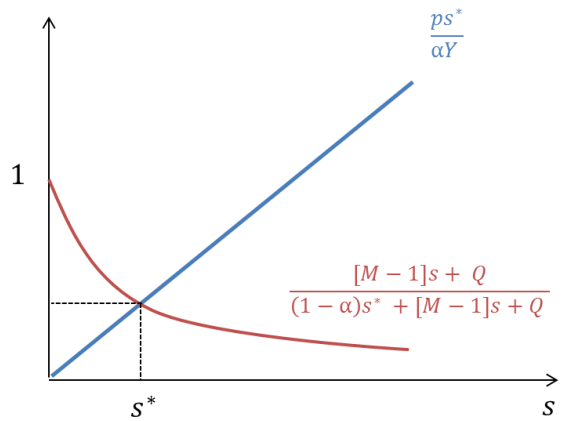



Figure 1a: An Implicit Analysis of the Exogenous Population Equilibrium

Figure 1a confirms that income (Y) appears as a linear interaction with seed effort decisions. Those with higher incomes expend an above average effort whilst those with lower incomes less so. We use a set of reasonable parameters (runs of which are not shown here) to confirm that by introducing heterogeneity of income, the aggregate investment efforts falls relative to when income homogeneity exists. Moreover, the effect, constituting a convergence towards social efficiency, rises as we increase the neighbourhood size. This result adheres with the theoretical predictions described above, and can be attributed to the contest element of our neighbours' utility functions. Under conditions of homogeneity, all neighbours have an equal endowment with which to compete. However, as incomes are transferred to create an unequal society, the feasibility for less endowed neighbours to actively engage in the contest is lessened. In a limiting case where all income would be transferred to one individual, the Nash Equilibrium would converge to the first-best solution and the contest is effectively eradicated from the neighbourhood. Of course, an equally pertinent finding realises that, even if the average income of a neighbourhood is held constant, there is a significant *redistribution* of effort expenditures when income heterogeneity is introduced.

Our model began as one of great simplicity, containing a number of convenient assumptions yet the above analyses have enabled us to explore the impact of relaxing many of these restrictions. These investigations have enabled us to derive a set of sound

conjectures of when and by what extent competing neighbours feed birds in their gardens to a greater and lesser extent. Furthermore, we have been able to analyse when our 'autonomous neighbourhood' finds itself feeding above, below or at the threshold advocated by the social optimum. This is widely dictated by two competing effects; contest-driven competition and public goods-fuelled free-riding. Neighbourhood size ($M$), natural food substitution ($q$) and socio-demographic heterogeneities ($Y$) can all impact upon the extent of the inefficiency and thus are all important factors to consider before advocating any policy recommendation. In the final section we discuss some empirical applications and implications of this model and draw some conclusive remarks which we hope will hold some poignancy for the field of environmental economics.

## 3. Applications and Conclusion

*Overview*

The under-provision of public goods when dependent upon private voluntary contributions is a well understood phenomenon and discovering a solution to this issue poses a sizeable social, economic and political obstacle. Environmental goods are no exception, and attempts to make private organisations or individuals invest adequate time or finances in the procurement or conservation of natural public resources typically falls short of the required standard. Previous studies have already shown that one mechanism which may partially alleviate this disinclination to contribute involves manipulating the 'impurity' of a good. When executed correctly, an individual should hold a greater incentive to contribute because they can simultaneously derive some form of private utility through this action. This notion has been used to explain how instances of charitable donations (Sieg; 2012), environmental offsets (Kotchen; 2009) and lottery fundraising (Morgan & Sefton; 2000) can procure higher thresholds of revenue than traditional economics would predict.

The theoretical model in our paper employs a further facet, contests, as a way to boost private incentives for contributing to public goods. Using bird-feeding as a motivating example, we illustrate how an individual's contribution efforts will depend upon two opposing mechanisms. We define these as 'the contest effect' and 'the public goods effect'. When compared against a first-best solution, these forces should create over-provision and under-provision respectively when analysed as individual actions. However, our analyses have shown that it is possible to combine these two mechanisms within one model in such a way that their effects can partially or completely counteract one another. An instance of perfect offsetting occurs when nature exhibits constant avian returns to scale from food stock alterations. When instead we have decreasing or null returns to scale, our model illustrates a domination of the public goods effect by the contest, leading to a level of provision (or effort) deemed excessive to that which society warrants. This ecologically plausible scenario is a far cry from the usual dilemma of insufficiently procuring environmental resources.

This is also of great importance from a policy perspective. As an environmental social planner, realising how to achieve socially desirable objectives could hinge upon many context-specific facets. The necessary advisory action may be altered or even reversed when applied to a location where neighbours are more or less heterogeneous, where the endowment structure is endogenously influenced (for example by garden size), and where the bird species are of a different level of scarcity, diversity or ornithological habit.

*Applications*

Whilst our analyses have solely applied this model to bird-feeding, there is no reason to believe that our theory cannot be extended to situations beyond this example. Indeed, there are a variety of relevant problems within the field of environmental economics where the competing impacts of public goods and contests could be modelled along the lines presented here. In each case, society can use the competitive nature of private individuals to establish a greater level of effort or expenditure which simultaneously secures a greater level of the associated public good. Potential instances of this include energy efficiency (Allcott; 2011), eco-tourism, grouse-shooting and wildlife volunteering (e.g. toad rescues www.bbc.co.uk).

Allcott's study provided individuals with information on their peer-relative energy efficiency. This is another example of where a relatively cost effective behavioural mechanism can be implemented so as to drive competitive individuals toward socially advantageous outcomes. The study found that by raising each resident's awareness regarding their approximate energy efficiency created a private adjustment in action estimated equivalent to a 1-2% drop in energy usage. Furthermore, many of the alterations were simple and well-known acts, showing that imposing competitive stimuli can create fairly cost-free and self-beneficial impacts for the private individual, whilst at the same time generating desirable public advantages.

Another example which illustrates the poignancy of competition in enabling the private provision of public goods relates to the litter rebate mechanisms established in developed societies such as Germany. This Government introduced legislature which entitles people to a refund when they return the packaging of certain products, such as soft drinks' plastic and glass bottles. One unforeseen implication of this policy has been that, in many public places, a social norm has arisen whereby people will leave the packaging of these goods as an act of charity. The perception is that the litter will be collected by those who are more in need, who will then receive a form of payment for their action. Let us apply this example to our model. The contest we attribute to the efforts of competing litter-pickers. The environmental public good relates to the removal of unsightly litter from public areas. Let us assume that litter levels are fixed in a given area (akin to the Exogenous Population Model of this paper). If no payment exists, we would expect an under-provision of effort by citizens relative to the social optimum. Litter is left unpicked and the public good is insufficiently provided. If instead a very small rebate is paid, then we should expect

a small reaction to this. Those with very low marginal value for time invest their efforts collecting the packaging to receive the associated payments. However, we would not expect this to completely eradicate litter. By contrast, at a very high rebate rate, there is now a sizeable private incentive to retrieve litter. Individuals are driven by these payments, but are also in direct competition with each other. The consequence of this will surely be an over-exertion of effort, demonstrated through agents searching for litter in areas absent of packaging, or through duplicated search efforts. Whilst this will mean the public good objective is met (i.e. litter is all removed), this will have been achieved in an effort-inefficient manner relative to that which the social optimum would dictate. Overall, our analyses would lead us to assume that an equilibrium rebate rate should exist whereby the level of effort employed by citizens exactly matches that required to eradicate all litter from public places efficiently. However, the contest and associated private monetary incentive to retrieve litter will cause this equilibrium rate to be lower than if no such dynamic existed. We assume the level of litter to be exogenous, yet it is plausible to adapt this example so that litter put down is endogenous. This would resonate with a charitable German population who discard more litter in public places in response to seeing a high concentration of litter picking in society. Advocating such action is in fact promoted in Germany (see http://www.pfand-gehoert-daneben.de/ for an instance of this). This example holds even greater impetus from a policy perspective. Whilst employed in Germany, many societies which are similar have not introduced such schemes. This nicely shows the way in which an institution might manipulate the private incentives of individuals in order to derive social constructs which simultaneously solve classic public goods dilemmas.

Our model of offsetting effects may also be of interest to other areas in economics. One of these would be the advertising decisions of rival firms. An area already explored by competition economists (Grossman & Sharipo; 1984; Simbanegavi; 2009), this industry has a similar public goods dilemma. The difficulty lies in establishing whether aggregated private advertising efforts of firms are excessive or inadequate relative to the socially advisable level. Excessive advertising primarily arises when strong competitive tendencies exist between substitutable products, whilst inadequate advertising will occur when the promotional efforts of one firm provide extreme public spill-overs to those of allied products, facilitating extensive inter-firm benefits. Understanding how these two factors interact within an industry will allow competition authorities to understand when the intensity of advertising is too great or is insufficient, and potentially also suggest how this imperfection can be remedied.

Whilst each of these examples show likenesses to our motivating example, the transferability of our findings to these situations hinge of a number of factors. One of the most important of these is the mechanism by which a contest is formed. In the bird-feeding case, the competitive drive of neighbours is borne from their self-motivated desire to attract birds to their own garden. In the three examples detailed above, we see that the derivation

of a contest occurs through management structures, status relativities and product substitutability respectively. However, the purpose of this section is to illustrate more broadly that the role of competition can be instrumental in combatting the free-riding tendencies synonymous with traditional public goods theory. Nevertheless, one important research recommendation of this paper is to establish whether, and to what extent, the contest structure itself influences people's decisions. This should help ascertain the degree to which our bird-feeding model is capable of representing these assimilated cases.

*Conclusion*

The above section has attempted to provide a number of alternative examples which our model might look to represent. Another important aspect of this paper is to highlight the necessity of developing a sound understanding regarding the dynamics of human interaction with the environment. This involves grasping *why* people do or do not engage in environmental activities and the underlying reasons for their motivation or disinclination. Only upon achieving this will it be feasible to deliver or conserve our natural resources at economically and socially efficient levels. By way of example, it would have been hard to explain our findings without realising how neighbours yield utility through the 'nature connectivity' (Dutcher et al; 2007) they establish when engaging with local wildlife. It is only once we appreciate that individuals primarily gain satisfaction from birds coming to *their* garden that we are able to describe and defend the notion of a contest effect and see instances of optimal or even over-provision of the impure public good. Urging conservationists, politicians and other policy directors to capture the detailed underpinnings of people's interconnectivity with nature is therefore the primary recommendation of this paper. Until this has been established, it will not be feasible for accurate and insightful environmental proposals to be devised.

The paper also illustrates the opportunities which environmental economists must take regarding the 'manipulation' of private motivations. Natural resources are fast decreasing, and the retention of those which still exist will not be possible unless we use all the available tools at our disposal. Where a population exists who are prepared to pay and there is a mechanism whereby payment is possible, this opportunity must be embraced by the field.

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