THESIS

EVALUATING THE EFFICIENCY OF CONSERVATION EFFORTS: A FRONTIER REGRESSION APPROACH

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ABSTRACT

EVALUATING THE EFFICIENCY OF CONSERVATION EFFORTS: A FRONTIER REGRESSION APPROACH

Conservation efforts in the United Kingdom began in 1949 with the Nature Conservancy Act. The goals of this legislation were to preserve natural areas and areas inhabited by threatened and endangered species, as well as provide the opportunity for research. The objective of this thesis is to apply stochastic frontier analysis (SFA) to better evaluate the efficiency of threatened and endangered species conservation efforts. SFA will build upon previous analysis that uses cost-utility analysis to measure the effectiveness of a Species Action Plan (SAP). This new application of a SFA will help improve the assessment of efficiency of government programs, and is an improvement from existing conservation efficiency measures because the analysis does not require assumptions of the value of a species. The absence of assumptions on value helps the analysis reflect actual funding decisions and better allows for interspecies comparisons. The results will not only provide a more robust analysis, but also have practical application in evaluating the efficiency of a species recovery and give conservation efforts a better measurement tool. With an effective efficiency measure in place, programs will be better judged and shifts in funding or changes to specific plans are possible.

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1. INTRODUCTION

Species conservation in the United Kingdom can be traced back to the beginning of the 19th century; the *Nature Conservancy Act of 1949* is widely regarded as the beginning of government mandated conservation. This Act established National Parks throughout England and Wales which were devoted to the conservation of rare species and the potential for expanded scientific research. It also created Sites of Specific Interest (SSSIs) which are areas in which fauna and flora are represented, and are home to rare species. This policy placed the responsibility of conservation on landowners, and trusted that landowners would behave in a way that preserved the natural sites. The government had no authority to change the use of land, and it was the decision of the landowner to use the land in the way they saw best fit.

The next step in legislation towards increased conservation was the *Wildlife and Countryside Act of 1981*. The formation of this Act was in part due to the UK entering the European Economic Community (EEC) which made all members follow certain economic and environmental guidelines. The 1979 *Bern Convention* and *Conservation of Wild Birds* Directives were integral in the eventual passing of the *Wildlife and Countryside Act of 1981*. The *Bern Convention* required the conservation of wild flora and fauna, as well as the protection of endangered species and their habitats. The *Conservation of Wild Birds* Directive had similar goals with the protection of threatened species and the creation of Special Protection Areas (SPAs). The *Wildlife and Countryside Act of 1981* also saw the creation of Super SSSI's, but still did not allow the government to require a change of use by the landowner. The Act did allow the government to encourage landowners to use the land in a way that matched the conservation goal.

The current structure of conservation in the UK has become diversified with an increasing number of different agencies. The Joint Nature Conservation Committee (JNCC) oversees the many different conservation efforts. One of the major parts of this committee is the UK Biodiversity Action Plan (BAP), which meets the required standards of the Convention of Biological Diversity. The UK BAP has grown to include "391 Species Action Plans, 45 Habitat Action Plans and 162 Local Biodiversity Action Plans with targeted actions." Each species has a Species Action Plan (SAP), for which a plan is laid out and periodic updates on the status of the species is conducted.

In 2010 the UK government spent £560 million on biodiversity up from £247 million in 2000. This increase reinforces the message that species conservation and biodiversity are an important goal. Currently vertebrates account for 83.5% of funds with mammals and birds taking nearly 75% of funds, even though they account for a relatively small number species included on the threatened or endangered list. The increased awareness of the last 20 years has helped stop the rapid loss of species, but many species are still in danger. The 20th century saw a massive loss of biodiversity; over 100 species in the UK have gone extinct (Laycock et al. 2009). The following figure helps illustrate the current state of species conservation in the UK; trends of all species are shown, so it is possible that a species could both improve and decline in the same graph.

Species conservation trends

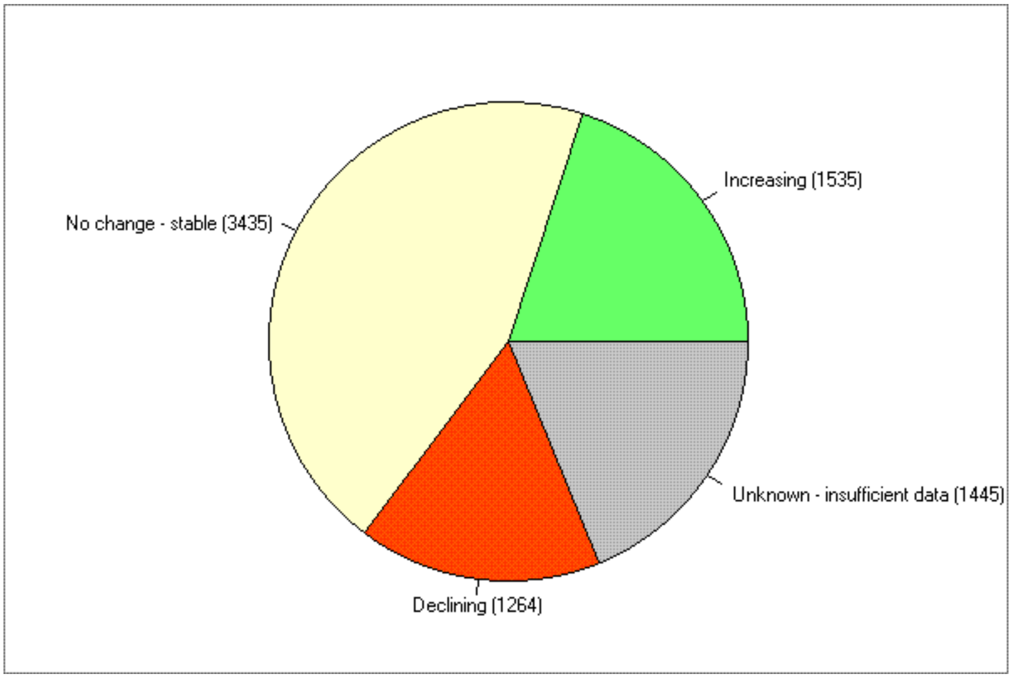

Figure 1: Graph showing the trend of species over the 20th century

Current research focuses on the effectiveness of an SAP. The goal of these programs is to preserve threatened and endangered species and their habitats. While the budget seems to be large, funds are extremely limited which makes proper allocation crucial to success. Previous research indicates that some species have made a full recovery, while others have made no, or negative progress, with many species falling somewhere in between. The most common measure of the effectiveness of a program is comparing the growth of a population from one year to the next. When a species continuously sees an increase in population across years, the program is deemed effective. The quicker the increases in growth, the more effective the program regarded. A leading measure of output that has been created to show the effectiveness of an SAP is the Conservation Output Protection Year (COPY). This measure illustrates the total increase in species population across years.

The effectiveness of a program is important, but with constrained funds a measure that includes cost is needed. Economics offers interesting insight into incorporating limited resources into the investigation of effectiveness. Technical efficiency is based on the principle of using resources to maximize the production of a good or service while minimizing inputs. Technical efficiency is particularly important in this paper because it represents a change in thought from previous research which focused on the effectiveness of conservation. The introduction of technical efficiency will allow policy makers to determine if more output could have been achieved with the same funds. Current methods derive an efficiency measure, but are not able to look at technical efficiency. The SFA rankings use technical efficiency to show which programs could have produced more output with their species biological traits. Currently efficiency measures only look at the output of a species compared to another species, without biological traits being considered.

A significant amount of the research done on species conservation has taken place in the realm of ecology. Most previous research derives an efficiency measure by dividing the cost of the program by the effectiveness measure. A common example of this uses COPY to measure the increase in output and divides by cost to create a COPY-efficiency measure. The COPY-efficiency measure gives cost per unit output, which researchers use to rate different programs. COPY-efficiency captures inefficiency, but is unable to comment on the technical efficiency of a program. In addition to the inability of COPY-efficiency to investigate technical efficiency, studies that use COPY-efficiency have an assumption of equal value of conservation across different species. This allows researchers to compare different species using the same units. Therefore, in their analysis the conservation of all species is equally weighted; the utility gained from protecting an otter is equal to that of a beetle, which is equal to the value of lichen. As stated before, this allows researchers to compare across species. The introduction of SFA makes it so that the equal value assumption is not needed.

If the equal value assumption is removed, previous research methods are unable to say whether the improvement for a given species was as efficient as possible, but only comments of whether an SAP was more cost-effective than another SAP. The use of Stochastic Frontier Analysis (SFA) allows us to judge true efficiency of a program, not a comparison of cost-effectiveness relative to other species. SFA in conservation provides insight as to whether or not the funds currently given to each species have been used in a way that maximizing output with minimized inputs. Our SFA measure does not need the assumption of equal value, but rather uses real world funding decisions to judge the efficiency of an SAP. The aim of this paper is to use efficiency analysis, using SFA, to see what programs had efficient allocation of resources which will ultimately allow for more informed funding decisions.

The COPY-efficiency measure currently used finds, almost without exception, that non-vertebrates are more efficient than vertebrates. Laycock et al. 2009 found that the top 29 most efficient SAPs in their sample were non-vertebrates, when using the COPY-efficiency measure. This may be generally true, but it is also a function of the value assumption discussed above and the allocation of funds. The COPY-efficiency measure divides output by cost to determine the ranking of a program; therefore more expensive programs are disadvantaged, all else equal. Seventy-five percent of funds go to mammals and birds, which put these species specifically at a disadvantage in COPY-efficiency rankings. This implies that if two programs have the same output but different costs, the program with higher costs will be deemed less efficient.

COPY-efficiency can successfully rank SAPs if all species are believed to have homogenous traits, but this does not match understanding of diversity across species.

Biologically it is more fitting to acknowledge that different species have different traits. The traits we are referring to, but are not limited to: mortality rate, fertility rate, home-range size, amount of the Kingdom the species inhabits. Current analysis excludes the differences from the analysis, which handicaps certain species. Large mammals take much longer to sexually mature than most invertebrates, and it is therefore reasonable to believe the mammals will have slower recovery rates. A brief comparison can illustrate this point. The European otter (*lutra lutra*) has small litter sizes and reproduces between the age of 3 and 15, with most of the breeding occurring between the ages of 6 and 9. The common beetle is sexually mature at between 7 and 14 day. The SAP program has been implemented in the last 20 years, which means only around 4 generations of otters have occurred and well over 500 generations of beetles have potentially occurred.

This simple example illustrates the importance of incorporating species characteristics. It may be that some species are inherently and naturally more expensive to save. SFA allows these traits to be accounted for and does not penalize a species for slower naturally slower reproductive rates. An additional strength of SFA is the relative cost of the program does not affect the efficiency of program because it is no longer using cost data only in the denominator. SFA has traditionally been used in industrial economics to determine the efficiency of a company and to determine if a company is underperforming with its resources. SFA is a natural fit for comparisons between different companies, within the same sector, because it allows researchers to compare efficiency of an organization recognizing that the infrastructure of each company is different.

This analysis lends itself to being applied to conservation efforts because the process can evaluate the efficiency of a species with the given funds. The analysis can then determine which species are performing optimally based on the allocation of resources given, not strictly in comparison to other species. Specifically, SFA allows us to find the inefficiency within an SAP, so that modifications can be made to the SAP. The SFA provides a theoretical maximum production level for an SAP and any inefficiency appears by the output being inside of the threshold maximum. Species characteristics can be taken into account and therefore more difficult species to save are not penalized. Some species may be more difficult or costly to protect even at full efficiency. Therefore it is possible that a species with a high ranking for COPY-efficiency may actually be operating a with a lower efficiency ranking calculated by SFA. SAPs that have a higher SFA ranking are more efficient and it may be optimal for policy makers to increase funds to those programs or apply the successes of the program to other species.

This thesis will proceed with the literature review, which will give a summary of the current literature and will show the foundation of the material I build on. The next section will describe the data that will be used to construct the SFA. The data ultimately used in this thesis consists of 38 different species of plants, invertebrates, and vertebrates, which is all of the species that had complete cost data. The methodology section will explain how SFA works and the theoretical underpinnings of the model. The empirical results and discussion sections of results section will show the results from the SFA and explain the significance of the findings. Finally, the conclusion will explain what the paper accomplished and the hopes for how the thesis will be used.

2. LITERATURE REVIEW

The goal of conservation is to most effectively allocate scarce resources across different species; this is required to most effectively meet the goal of conservation. The analysis of effectiveness and using it to develop efficiency, in conservation is relatively new, and like most new objectives, has not found a universal method that best judge a conservation plan. As funds for conservation projects have increased, there has been an increased push to find better ratings of programs. Most comprehensive government programs for species conservations and biodiversity were created in the last 25 years. According to Pullin and Knight's 2000 article, there is still a disconnect between ecological research and the atmosphere of application of species conservation. Conservation biology has formed as a theoretical study and never yet to be combined with the budget limitations and targets set by Species Action Plans (SAPs). Until the last decade, lack of data and the youth of most conservation efforts made effective analysis and critiques of programs impossible. Different model structures have been created to try to address limited resources and other real world hindrances to conservation.

We will see many of the advancements in measuring cost-efficiency come from the healthcare sector. This link is fitting, as both conservation and public health are studies of crisis, with no easy units of measurement. Many of the methods used in species conservation today are derived from the notion that a dollar measurement is difficult to derive and perhaps even more difficult to interpret. Improvements in the analysis of conservation have been impressive over the last 15 years, from using traditional cost-benefit analysis (CBA), building to cost-effectiveness analysis (CEA) and cost-utility analysis (CUA), the latter two created from public health studies.

An integral part of economic analysis in recent decades has been CBA, and the basic framework is still found in species conservation analysis. There have not been many papers that have explicitly used CBA in the context of species conservation, but it is still worth discussing to build to more specific methods.

CBA investigates whether the benefit of a project is greater than the costs. It is clear that this concept can be applied in many different arenas. The cost-benefit objective can greatly simplify a question by straightforwardly comparing costs to benefits, but not all subjects lend themselves to such a straightforward comparison. CBA has also been adjusted to include possible benefits that do not easily have a market value. Non-market valuation is crucial in evaluating many projects in environmental economics, where a market value is often time not the only value needed to be considered.

Monetizing values has widely been done using the contingent valuation method (CVM), which uses surveys to calculate a willingness to pay for a good. This flexibility makes CBA, and other methods that use CVM, very useful, but despite its versatility, it is not suitable for all projects. CBA has the advantage of giving a dollar value so that all alternatives are easily comparable. This simplification is extremely beneficial, but there are some circumstances where monetizing possible objectives cannot be done in a comprehensive manner. CBA may fail to account for the many intricacies involved with species conservation. This method has limits and many specialists find that monetizing species conservation values is ineffective and does not appropriately measure benefits. It is also difficult to derive an accurate willingness to pay, using CVM, because it is possible that respondents will not be familiar with many species and not have a large enough information set about ecosystem dynamics to make a informed decision.

CEA uses many of the strengths of CBA, but does not rely on monetizing the benefits of alternatives. CEA looks at finding the least cost alternative to an objective for a given level of output. This least cost alternative can be thought of as evaluating the opportunity cost of the objective. When funds are allocated to a species, CEA compares the allocation with other possible decisions, to ensure the best selection was made. Instead of providing a market value, like CBA, CEA provides a non-monetary output value.

Because this analysis uses the principle of opportunity cost, data must be available to compare against other alternatives. CEA is best used to determine whether a specific project is operating at the least cost, which is desirable in species conservation, but ultimately lacking because of the additional data needed not enough discussion of output. In the case of conservation, CEA would investigate the least cost solution to reach a specific effect.

A specific example will be helpful to show how specifically non-monetary values can illustrate success. Macmillan et al. (1998) was an early, leading CEA study that examined the cost-effectiveness of restoring woodlands in Scotland. The paper relied on forestry experts to establish guidelines of success measures so that numerous sites can be compared. The expert panel created a set of measures that indicates the health of the ecosystem. These measures include genetic integrity, species composition, area of new woodlands, among many different indicators. These measures are then weighted and applied to various projects to measure their success. Therefore, success is measured by how many of the weighted indicators of ecosystem health are met. Over 200 different sites were selected and received different types and levels of potential restoration methods. The study ultimately finds that government aid is negatively correlated with restoration of woodlands.

The foundations of CEA, which make it ideal for use in conservation, are discussed by Pullin and Knight. They emphasize the gap between theoretical and academic ecology and application of conservation projects. The authors suggest looking to public health for practical and applied methods of review for conservation projects. In medicine many different cures have been found for the same illness, and a method for measuring effectiveness was needed to ultimately investigate a benefit-cost ratio.

The fear is that without an objective method of judging the efficiency of a projects funding, the funds will be misallocated and further biodiversity will be lost. Pullen and Knight searched for a systematic review of conservation efficiency in leading conservation biology journals and found none. While a few authors did investigate methods of review, none were widely accepted and thus a consistent process for analysis has never been created. This lack of systematic review makes it impossible for consistent analysis to be done, which will allow the unintended misuse of funds to continue. Applying methods created in public health will create far more consistent review methods, and a shift toward these methods has been observed in the last decade. In the 1970's the study of medicine began searching for and compiling evidence for what works and what is the cost.

CEA has been used to compare different SAPs, even though it is widely accepted that other methods may be preferable, Cullen et al. (2004). Several papers have used CEA to evaluate the cost-effectiveness of various SAPs, most notably in the article *Evaluating the cost-effectiveness of conservation: The UK Biodiversity Action Plan* (Laycock et al. 2009). This study uses CEA to measure the effectiveness of a program at meeting the predetermined goals of conservation laid out in the 1994 UK Biodiversity Action Plan. The paper explains the new usage of CEA, explaining its adaptation from healthcare economics.

Laycock et al. (2009) is also one of the first attempts to measure and compare efficiencies of different SAPs. This was done by deriving an effectiveness measure and dividing by the cost of the program. The effectiveness measure used in this paper uses the percentage of the target that is met and then multiplies it by the importance of that specific target. When cost is incorporated they achieve a benefit per unit cost figure. This appears to be a useful indicator, but the rigidity of the effectiveness measure leaves the result inflexible because of the inability to vary the study over different time increments and units of output, Cullen et al. (2004). CUA will ultimately be a better indicator because it incorporates the variable lengths of time and output. Even though CEA is used in this paper, it still adds to the literature by realizing that the efficiency of a program is a critical component in the conservation of biodiversity.

CEA is best used for the analysis of a specific species' conservation program, as shown in the Macmillan et al. paper, instead of comparing effectiveness of different SAPs, as it is difficult to imagine the next best alternative when the species differ. In CEA, effectiveness relates to the total increase of the species, which is not necessarily the goal of healthcare or of species conservation. CEA looks at the total gain in population numbers of a program. Society is ultimately interested in the conservation of biodiversity, not an indicator that informs how many species were saved, as this number would be out of context across species. This is why CUA has become the generally accepted method to evaluate species conservation methods. CUA is useful in species conservation because it can incorporate different species traits, such as fertility and mortality rates, because it is measured as an increase in utility, not number of species. This allows the effectiveness measure to capture species differences and exhibit the flexibility of analysis which is needed for multi-species comparison.

CUA, like CEA, was also founded in public health studies, and is currently the leading method to measure effectiveness of an SAP. CUA has been used in the public health analysis for almost 30 years. The measurement of a medical procedure is most easily measured in utility; it is difficult and controversial to imagine a way to monetize an outcome of a medical intervention. Instead, the effectiveness of a procedure is measured by the quality-adjusted life-years (QALY). QALY incorporates both the increase in the number of years of life and the quality of these years after a medical intervention. QALY allows the comparison of different medical interventions, which can then be compared to the cost of the procedure to give insight into the efficiency of the different alternative. It would therefore be possible to compare the effectiveness of a kidney transplant versus dialysis. The measure would be in terms of some level of utility. It would also be possible to compare the increase in utility of a kidney transplant versus and lung transplant or any other medical procedure. This is possible because QALY is represented as an increase in utility over time.

The QALY index uses a scale of 0 to 1 to illustrate the health of the person, where 0 is death and 1 is totally healthy. Cullen et al. provide a simple example of calculating QALY in their paper: *Measuring the success and the cost effectiveness of New Zealand multiple-species projects to the conservation of threatened species*. The authors explain, that if a medical intervention increases a person's health from .6 to .9 for 10 years the QALY indicator is calculated as such: (.9-.6)*10=3.0 The improvement in health and the total numbers of years the intervention is beneficial will dictate a higher QALY score.

Cullen et al. (1999 and 2001) introduce the concept of CUA and the QALY index, which were converted for use in species conservation, with the Conservation Output Protection Year (COPY) measurement. The leading author in both papers, Cullen et al. (2001), explains, "COPY serves the same function as QALY in health-care evaluation in the sense that it allows the effectiveness of unlike activities to be compared." Like QALY, COPY is able to vary in time and allows for different types of programs to be considered against each other. This means that programs with different goals can be compared; the utility of preserving a forest can theoretically be compared to preserving a large mammal, with an infinite amount of topics that can be substituted for analysis. This versatility is what makes CUA the optimal tool for multi-species analysis.

As with QALY, a simple example of how COPY works will help illustrate the versatility as well as the simplicity. Suppose a panel of experts looks at the effectiveness of an SAP and finds that it went from .4 to .8, where 0 is extinct and 1 is the ideal population size, over a 15 year span. The COPY is shown by: (.8-.4)*15=6. A higher copy value, all else equal, means a more effective project. The initial numbers are determined by conservation biologists or other experts who analyze species populations. This allows many different projects to be compared, but it the for SAP analysis the widest variation is between plants and vertebrates.

In the first paper to present COPY, Cullen et al. (2001) the authors recognize that an effectiveness measure is not the only valuable way to compare programs across species. An efficiency measure is created by dividing COPY by the cost of the program, which produces COPY-efficiency. This creates a benefit per unit cost, which will inform decision makers of which program has the most output per dollar. This implies that programs with high COPY-efficiency should receive more funds, and low COPY-efficiencies should receive fewer funds or make changes in how conservation efforts are pursued.

COPY-efficiency was used most recently by Laycock et al. (2011). This paper looks at COPY and COPY-efficiency for 38 SAPs, and ranks the programs in terms of COPY-efficiency.

They follow the example provided above by Cullen et al. Surveys were sent to various expert panels in order to calculate the COPY effectiveness in addition to the cost of the program for as many species as was possible. The authors derive COPY-efficiency, to show which programs are most efficient and make recommendations based on these findings. They find that generally non-vertebrates are more efficient than vertebrates and therefore in order to maximize efficiency funds should be transitioned to the more efficient programs. However, this method of efficiency lacks necessary information about the species.

Current literature does an excellent job of calculating the effectiveness of a program, but lacks power when converted to efficiency. It is clear that species with a larger budget are penalized in the COPY-efficiency statistic. Using stochastic frontier analysis (SFA), cost can be incorporated by regression analysis instead of simply by division. Varying species traits are accounted for in some respects in the COPY statistic, but are insufficiently recognized in COPY-efficiency.

METHODOLIGIES

This section will discuss the models and the theoretical underpinnings of the models used in this thesis. The main methods used are Conservation Output Protection Year (COPY) as the measurement for the effectiveness of a program, and Stochastic Frontier Analysis (SFA) which will be used to rank programs in terms of efficiency. These methods will be explained, and their functional forms shown and discussed.

The COPY measurement uses cost-utility analysis (CUA) to provide an effectiveness measure that allows multi-species comparison. The goal of COPY is to provide a common unit of measurement so that different species can be compared. As explained in the literature review, the COPY measure in expressed as utility rather than in dollars or units of species saved. This allows researchers to begin multispecies conservation analysis.

The COPY measure is derived through survey methods, where the participant evaluates the health of a species based on the short survey. The COPY measure takes the functional form of:

$$COPY_i = \sum_{t=0}^{T} \left[\left(S_{itw} - S_{itw_o} \right) (1+d)^t \right]$$

S_{itw} represents the conservation status of species *i* in year *t* when conservation efforts have been made, whereas S_{itw_o} represents the conservation status of species *i* in year *t* when no conservation efforts have been made, or the beginning of the studies time span. An example will help illustrate the formula. If a species starts with S_{itw_o} being .3 and S_{itw} equalling .6 over a ten year span, the COPY will be (.6-.3)*10=3.00.

The first piece of the COPY formula are the relative health parameters, S_{itw} and S_{itw_o}, taking values from 0 to 1, that illustrate where the population of the species is positioned, 0 is extinct, 1 is not threatened. The general method for creating a species health continuum comes from Cullen et al. (2005), but the exact continuum I will use comes from Laycock et al. (2011), and takes the form:

Health Continuum Chart	
Health of Species Category	*Range on continuum*
Extinct (EX)	0.00
Extinct in the Wild (EW)	0.01–0.17
Critically Endangered (CR)	0.18–0.33
Endangered (EN)	0.34–0.50
Vulnerable (VU)	0.51–0.67
Near Threatened (NT)	0.68–0.83
Least Concern (LC)	0.84–1.00

Figure 2: Chart showing the health continuum scale for SAP's

The categories are based on the International Union for the Conservation of Nature's (IUCN) Red List version 3.1 that categorize the health of a species population. Cullen et al. (2005) use a quadratic scale, rather than linear as shown above, so that gains made in more threatened species carried a higher relative weight; the linear scale has an essentially equal sized categorization of 0.16. The quadratic scale fits better with the more detailed version of the health continuum used in that study, but the linear categorization, works best in this simplified case. The data for most of the species in this study only spans 10 years, so many of these species may have made gains, but not enough to enter a higher category. The Laycock et al. (2011) solves this problem by also asking participants to rank the species gains from within each health category. Therefore any gains that are made but are not sufficient to enter a new category will receive the higher bound of the initial category, whereas if population squarely in the same category the species will receive a number closer to the lower bound.

Current literature includes the cost of the program with the calculated COPY value to create COPY-efficiency. This is a COPY cost ratio that creates an output per dollar figure. The formula for the COPY-efficiency measure is shown as:

$$COPY_{efficiency} = \frac{\sum_{t=0}^{T}[C_{it}(1+d)^{t}]}{COPY_i}$$

where,

$$C_{it} = Cost\ of\ SAP_i\ in\ year\ t$$

$$d = Discount\ rate$$

A lower COPY-efficiency figure means the program is more efficient. The above form is shown with a discount figure which can be selected based on the given requirements of the agency using the statistic.

SFA will then use the COPY measure as the dependent variable and use regression analysis to show the inefficiency of a program with the characteristics and traits of a program taken into account. SFA was created by Aigner et al. (1977) and Messusen and van den Broeck (1977) with separate publications within the same year. The model was created in order to model, and account for, inefficiency. SFA uses the concept that a production activity has a theoretical maximum frontier for a given set of resources. Stochastic Frontier Analysis is specifically important because it places the production frontier at a random place based on the stochastic specifications of the model. If the producer is operating at any point inside of this maximum, the relative distance can be referenced as random noise beyond control and inefficiency. The analysis has grown to where these two factors that cause a firm to produce inside the frontier can be split, and the inefficiency can be isolated and quantified. It is this inefficiency term that this thesis will focus on and use to illustrate efficient SAPs.

It is important to show the general functional form of the model, so that the process can be fully explained; the functional form of the model can be shown as:

$$y_i = \alpha + \beta' x_i + v_i - u_i = \alpha + \beta' x_i + \varepsilon_i \, ,$$

Where,

$u_i = |U_i|, U_i \sim N[0, \sigma_u^2], \quad v_i \sim N[0, \sigma_v^2], \mathit{and\ u\ and\ v\ are\ not\ correlated}$

The above is specifically for the half normal distribution. The disturbance term ε_i consists of two terms v_i and u_i. v_i is a two-sided error term that accounts for random noise, while u_i is a one-sided error term that accounts for inefficiency. u_i is normally distributed, but v_i can take numerous distributions; this thesis presents v_i as half normal, truncated normal, and exponential distributions. v_i and u_i are not correlated, without this assumption a joint pdf cannot be formed; this is to say that the joint pdf cannot be formed unless the two are independent of each other. The assumption of zero correlation between u_i and v_i is in place to show that all inefficiency is attributed to the u_i term. The u_i term is subtracted from the observed output, y_i, which matches what we expect because the inefficiency of the model is reducing the output possible by the producer. It follows that the maximum stochastic frontier, which is a firm that has no inefficiency, is:

$$y_i = \alpha + \beta' x_i + v_i$$

The above simply shows the production frontier with zero inefficiency.

A further discussion of the interpretation u_i will be helpful in preparation of the formal estimator tool. The inefficiency term, u_i, represents a relative efficiency. u_i can be thought of as an ordinal number rather than a cardinal; therefore, the relative magnitude is only important for the ranking, but no value can be extracted from the scale of the value. It is possible to run SFA with logs so that the percent of inefficiency can be shown. This is not possible in the context of this thesis because of the numerous zero values. The u_i term has cost already incorporated; therefore, if two species have identical u_i they would have the same relative efficiency ranking.

Three forms of SFA were used in this thesis, the half normal, the truncated normal, and the exponential distributed. The half normal assumption is based around the idea that u_i can only take non-negative values. The half normal assumes mean zero and standard deviation σ, this aligns with the standard assumption of the normal distribution. The truncated normal also truncates the error to one side, but has mean μ and standard deviation σ. The mean centered at μ rather than zero is what differentiates the truncated normal from the half normal. The exponential is a form of a gamma distribution, where again the values are bound to one side of the theoretical maximum. The mean and the standard deviation remains the same, and is not the mean and standard deviation of the transformed exponential. If y_i is the theoretical maximum frontier, we cannot have a disturbance term that puts us outside of this.

The actual model takes three forms throughout the paper. The first model is the most simple, and as the paper continues the model evolves to include more variables. We are not concerned with cross-effects between cost and other independent variables, which could cause multicollinearity. Multicollinearity suggests possible correlation between independent variables. This would change our standard errors and ultimately our t-statistics, but these are not crucial to the paper, and the variation would likely be minimal. The simplest version uses cost as the only independent variable. This will act as the most basic investigation into the merits of SFA in species conservation. The first form is shown as:

$$COPY = b_1 + b_2 * Cost + v_i - u_i$$

The second form of the model includes the class variable, which accounts for whether the species is an invertebrate, vertebrate, or plant. In order to do this the species were categorized and dummy variables were used in the regression. The specific model used in this thesis is shown as:

$$COPY = b_1 + b_2 * Cost + b_3 * Plant + b_4 * Vertebrate + v_i - u_i$$

The third, and most inclusive, version of the model also includes the percent of the Kingdom the species inhabits. This was done by splitting the habitats size into three possibilities local, regional, and ultra-regional. This model takes the form:

$$COPY = b_1 + b_2 * Cost + b_3 * Plant + b_4 * Vertebrate + b_5 * Local + b_6 * UltraRegional + v_i - u_i$$

In order to calculate the inefficiency for each species, which will allow us to rank Species Action Plan (SAPs) in terms of efficiency; we must plug the values from the regression output into the Jondrow Estimator, Jondrow 1982, of $E[u|v-u]$. The Jondrow Estimator uses the likelihood function to estimate the disturbance term ε. Once an estimate for the disturbance is found, it can be plugged in to find the part of the disturbance that can is associated with inefficiency, which is denoted u_i. Manipulation of the maximum likelihood estimator (MLE) yields ε and λ, which will be plugged into the Jondrow Estimator to rank inefficiency of the SAPs. In order to demonstrate the MLE of the half normal distribution, the log-likelihood function can be shown as:

$$\ln L(\beta, \sigma, \lambda) = \sum_{i=1}^{N} [\tfrac{1}{2} \ln(\tfrac{2}{\pi}) - \ln \sigma - \tfrac{1}{2}(\tfrac{\varepsilon_i}{\sigma})^2 + \ln \Phi\, (\tfrac{-\lambda \varepsilon_i}{\sigma})]$$

While the Jondrow Estimator takes the form:

$$\hat{E}[u|\varepsilon] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\varphi(w)}{1-\Phi(w)} - w\right]$$

where $\varepsilon = v \pm u$, $w = \frac{\varepsilon\lambda}{\sigma}$, $\sigma = \sqrt{\sigma_v^2 + \sigma_u^2}$, $\lambda = \frac{\sigma_u}{\sigma_v}$

This allows us to estimate u, which is the part of the equation that identifies inefficiency, indirectly, as it is not possible to directly measure u_i. The larger the u_i term, the more inefficiency that is present in the SAP. Shown above we see that lambda is the standard error of u divided by the standard error of v, where u is inefficiency and v is noise. Therefore, this value effectively gives us a measure of skewness. The larger the lambda value the more likely that there is inefficiency within the system. It is not possible to say what lambda value proves inefficiency, but it is rather an indicator that is relative to each individual mode. With this information we can rank the SAPs based on how far that particular species is from their specific maximum frontier.

DATA

This section will discuss the data that is used in this thesis, and how it was collected. The majority of the effectiveness and cost data will come from the Laycock et al. (2011) paper. This paper looks at the effectiveness of species action plans (SAPs) in the United Kingdom. The data collected is for the time around 2005. In this study, surveys were sent out to relevant leaders of SAPs asking for the cost of an SAP, and questions concerning conservation gains. This thesis will also add control variable data to illustrate a more complete picture of conservation.

At the start of research there were 380 possible SAPs to participate in the survey. Of the 380 SAPs only 38 species were able to be used. This decrease is due to lack of survey participation, and also inability to be certain of SAPs to provide accurate information of expenditures for their program or the inability to empirically state the conservations status of the species. Therefore, the 39 responses are those who were able to provide the information needed for a conservation output protection year (COPY) value, and an accurate breakdown of the expenditures of the program.

The survey starts by asking participants to answer questions about the costs and expenditures of the program. Cost figures are sometimes not readily available to researchers, so this survey information is crucial to effectiveness and efficiency analysis. Survey participants are then asked to state how much direct expenditure was applied to the SAP. Surveys were sent out to the Lead Partner asking them to estimate the total amount spent directly spent on their SAP. The survey also asked participants to break expenditures into groups of several years, so an approximate timetable of when the funds were spent could be considered for the purposes of discounting.

The survey then asked participants about the conservation status for their specific SAP. As explained in the literature review the conservation status of each species was put into one of six categories ranging from extinct to least concern with a corresponding weight to status of the species. Table one, found in the methodology section, shows the categories that survey participants were asked to place their corresponding species. These categories help determine the weight of the COPY value. A further distinction is made for each category, where participants are asked to rate where the species is within each category. In this way the categories are more flexible by being a continuum, and also when the growth of the species is considered over time increases are recognized, even if they were not sufficient to increase into a higher category.

It is worth discussing that there exists a possible selection bias within the data. As explained before, only 38 out of the 380 SAPs responded. The low response rate could show that certain characteristics of the species that did respond were able to do so because of a select trait. There is no apparent bias, but with low response rate selection bias is always a possibility. The sample does show a relatively wide array of species, and mostly equal groupings among different species class and home range.

In addition to the survey and COPY statistics, data that helps divide species by class was used. The classes of species were broken down to vertebrates, invertebrates, and plants. This will help differentiate if species biological traits affect their COPY score. Data was also collected to measure the percent of the United Kingdom the species inhabit. The hope is to investigate whether or not inhabiting more land is inherently beneficial or costly to a species response. This percent in which the species inhabits was broken down into three categories:

local, regional, and ultra-regional or taking up the majority of the UK. This data was derived by viewing a map of the UK where the area in which a species currently inhabits is highlighted.

The results from the survey can be seen on the following table. This should help inform, of what the data looks like, and which animals saw population growth.   In addition to the COPY and cost statistics, the samples of species were divided into categories based on phylum, specifically invertebrate, vertebrate, and plant. The following table shows the species and what category they fall into.

Table 1

Data and Species Classification Table

Species (Page 1)	Cost	COPY	Species Category	Range Size
A ground beetle *Bembidion argenteolum*	960	0	Invertebrate	Local
A rove beetle *Stenus palposus*	960	0	Invertebrate	Local
A weevil *Melanapion minimum*	2000	0	Invertebrate	Regional
A weevil *Procas granulicollis*	2000	0	Invertebrate	Regional
Pashford pot beetle *Cryptocephalus exiguus*	2500	0	Invertebrate	Local
Red alga *Anotrichium barbatum*	3000	0	Plant	Local
Norfolk flapwort *Lophozia rutheana* *	3500	0	Plant	Local
Jumping weevil *Rhynchaenus testaceus*	5000	0	Invertebrate	Regional
A lichen *Calicium corynellum*	5000	0.1	Plant	Local
A leaf beetle *Cryptocephalus nitidulus*	5000	0.5	Invertebrate	Regional
7 spotted pot beetle *Cryptocephalus sexpunctatus*	5000	0	Invertebrate	Ultra-Regional
Marsh moth *Athetis pallustris*	6000	0	Invertebrate	Regional
Straw belle *Aspitates gilvaria gilvaria*	7550	0.07	Invertebrate	Local
Bast bark beetle *Ernoporus tiliae*	10000	0	Invertebrate	Regional
Leaf-rolling weevil *Byctiscus populi*	10000	0.4	Invertebrate	Regional
Norwegian mugwort *Artemisia norvegica*	10000	0	Plant	Local
Bog hoverfly *Eristalis cryptarum*	12000	3.89	Invertebrate	Local
Newman's lady fern *Athyrium flexile*	10000	0	Plant	Local
Glutinous snail *Myxas glutinosa*	12000	0	Invertebrate	Ultra-Regional
Hazel pot beetle *Cryptocephalus coryli*	20000	0.49	Invertebrate	Regional
A leaf beetle *Cryptocephalus primarius*	20000	0.22	Invertebrate	Local
Ramshorn snail *Anisus vorticulus*	25000	0.5	Invertebrate	Local
Narrow-mouthed whorl snail *Vertigo angustior*	24000	0.99	Invertebrate	Ultra-Regional
Whorl snail *Vertigo geyeri*	28500	1.8	Invertebrate	Ultra-Regional

Species (Page 2)	Cost	COPY	Species Category	Range Size
Deptford pink *Dianthus armeria*	39000	2.15	Plant	Ultra-Regional
Fen orchid *Liparis loeselii* *	34000	0	Plant	Regional
Yellow marsh saxifrage *Saxifraga hirculus*	60000	0.68	Plant	Ultra-Regional
Oblong Woodsia *Woodsia ilvensis*	164549	0	Plant	Regional
Vendace *Coregonus albula*	218000	1.1	Vertebrate	Local
Heath fritillary *Mellicta athalia*	252000	0.2	Invertebrate	Regional
Freshwater pearl mussel *Margaritifera margaritifera*	805000	0	Invertebrate	Ultra-Regional
Large blue butterfly *Maculinea arion*	1000000	0.64	Invertebrate	Local
Natterjack toad *Bufo calamita*	1064920	0.9	Vertebrate	Ultra-Regional
Curl Bunting *Emberiza cirlus*	1112800	0.93	Vertebrate	Regional
Basking Shark *Cetorhinus maximus*	1250000	0	Vertebrate	Ultra-Regional
Grey Partridge *Perdix perdix*	1640000	0.05	Vertebrate	Ultra-Regional
Otter *Lutra lutra*	2800000	0.16	Vertebrate	Ultra-Regional
Capercaillie *Tetrao urogallus*	7000000	1.75	Vertebrate	Regional

The COPY and cost figures will be used to create the COPY-efficiency measure that is used in previous studies to compare programs. The zero values for the COPY statistic represent no change in the conservation level of the species. The zero values cannot be differentiated in regards to efficiency, so current methods place all zero COPY values as the least efficient SAP. These zero values and general lack of participation among SAPs, only 10 percent successfully participated, make comprehensive analysis difficult. Government intervention may be required to require SAPs to participate. More observations are needed, if a truly comprehensive measure of efficiency is going to be achieved. This will ultimately lead to a more efficient program, as funding decisions become more evidence based.

RESULTS AND DISCUSSION

This section will present the results and discuss the implications of applying Stochastic Frontier Analysis (SFA) to species conservation. These results will show that SFA helps provide a more robust analysis by looking beyond the topical statistics of output and cost. The regressions will include whether or not the species is an invertebrate, vertebrate, or plant. This will begin to incorporate other species traits, possibly fertility, mortality, and the size of the species habitat, which will allow future conservation analysis to give a more informed discussion of efficiency. The aim of this paper is introduce SFA to species conservation, and explore the importance of incorporating species traits into efficiency analysis.

The limited number of observations, this study had only 38 Conservation Output Protection Year (COPY) and cost figures, limited the number of controls this study was able to incorporate due to issues dealing with the degrees of freedom. While it is not as large of a data set as desired, it is the largest data set currently available in the world. A further investigation of the incorporation of control variables will be able to occur once a larger data set in available, with more COPY and cost information. Attaining this data is possible because only 38 SAPs were able to be used out of 380 available at the time of this survey. This is equivalent to a ten percent response rate, which means a higher response rate should be able to be achieved. There are now nearly 1000 SAPs in the United Kingdom, so a higher response rate will yield a much more comprehensive analysis.

This thesis uses STATA to run the SFA, and will present the three most common forms of SFA, the half normal model, the truncated normal, and the exponential model. The truncated normal yielded the strongest statistics, meaning it was best able to overcome the small data set. The exponentially distributed and half normal SFA yielded nearly identical results to the truncated normal, which shows consistency in distribution outputs. The paper will present of a wide range of the outputs, building toward the idea that including more species biological traits will create a more robust analysis. In the appendix there will be further investigation of possible functional forms of the models. As described earlier, problems with the lack of data make it so that exact functional form is difficult. The methods described in the Results and Discussion section act as a baseline approach for analysis, whereas the appendix explores modifications that may ultimately fit the data better.

The first set of outputs regress the present value of cost on the present value of the COPY statistic. The outputs of the SFA processes are shown in the following table:

Table 2

Regression Results for the Basic Model

Independent Variables	Truncated SFA	Exponential SFA	Half Normal SFA
Constant			
Coefficient	.4386031	.457249	.4386031
Std. error	(.6121647)	(.2934003)	(.6121647)
t-stat	0.72	1.56	0.72
PV_Cost			
Coefficient	1.33e-07	1.33e-07	1.33e-07
Std. error	1.03e-07	(1.03e-07)	(1.03e-07)
t-stat	1.29	1.29	1.29
Lambda	.0078421	.0301198	.0078421
Sigma^2	.728283	.7284624	.728283

We see that the regression results are similar across all SFA processes. This output does not yield significant terms, but this is acceptable because the aim is to uncover inefficiency, not explain the production process. In order to effectively see the results of the regression, a table showing the corresponding rankings is following. The rankings are achieved using the Jondrow efficiency measure; the Jondrow estimator uses the lambda and sigma values to estimate the relative inefficiency for each species, u_i. The value itself does not give any significant result, but rather the relative size tells which species is more or less efficient. The efficiency number itself is of less interest than the relative ranking, meaning how it compares to other species numbers. It would therefore be possible to compare u_i values across all models, although this is not presented in this thesis. The first rankings table, on the following page, will present the COPY-efficiency measure versus SFA using the truncated normal, the half normal, and the exponential models.

Table 3

Basic SFA Analysis Rankings Table

Species Action Plan (Page 1)	Species Class	COPY-efficiency Ranking	Truncated Normal SFA Ranking	Exponentia l SFA Ranking	Normal SFA Ranking
A ground beetle *Bembidion argenteolum*	Invertebrate	21	19	19	19
A rove beetle *Stenus palposus*	Invertebrate	21	19	19	19
A weevil *Melanapion minimum*	Invertebrate	21	21	21	21
A weevil *Procas granulicollis*	Invertebrate	21	21	21	21
Pashford pot beetle *Cryptocephalus exiguus*	Invertebrate	21	23	23	23
Jumping weevil *Rhynchaenus testaceus*	Invertebrate	21	26	26	26
A leaf beetle *Cryptocephalus nitidulus*	Invertebrate	9	11	11	11
6 spotted pot beetle *Cryptocephalus sexpunctatus*	Invertebrate	21	26	26	26
Marsh moth *Athetis pallustris*	Invertebrate	21	28	28	28
Straw belle *Aspitates gilvaria gilvaria*	Invertebrate	11	18	18	18
Bast bark beetle *Ernoporus tiliae*	Invertebrate	21	29	29	29
Leaf-rolling weevil *Byctiscus populi*	Invertebrate	5	14	14	14
Bog hoverfly *Eristalis cryptarum*	Invertebrate	1	1	1	1
Glutinous snail *Myxas glutinosa*	Invertebrate	21	32	32	32
Hazel pot beetle *Cryptocephalus coryli*	Invertebrate	7	13	13	13
A leaf beetle *Cryptocephalus primarius*	Invertebrate	2	15	15	15
Ramshorn snail *Anisus vorticulus*	Invertebrate	13	12	12	12
Freshwater pearl mussel *Margaritifera margaritifera*	Invertebrate	21	35	35	35
Narrow-mouthed whorl snail *Vertigo angustior*	Invertebrate	6	5	5	5
Whorl snail *Vertigo geyeri*	Invertebrate	3	3	3	3

Species Action Plan (Page 2)	Species Class	COPY-efficiency Ranking	Truncated Normal SFA Ranking	Exponentia l SFA Ranking	Normal SFA Ranking
Heath fritillary *Mellicta athalia*	Invertebrate	16	16	16	16
Large blue butterfly *Maculinea arion*	Invertebrate	17	10	10	10
Red alga *Anotrichium barbatum*	Plant	21	24	24	24
Norfolk flapwort *Lophozia rutheana* *	Plant	21	25	25	25
A lichen *Calicium corynellum*	Plant	8	17	17	17
Norwegian mugwort *Artemisia norvegica*	Plant	21	29	29	29
Newman's lady fern *Athyrium flexile*	Plant	21	29	29	29
Deptford pink *Dianthus armeria*	Plant	4	2	2	2
Fen orchid *Liparis loeselii* *	Plant	21	33	33	33
Yellow marsh saxifrage *Saxifraga hirculus*	Plant	10	9	9	9
Oblong Woodsia *Woodsia ilvensis*	Plant	21	34	34	34
Vendace *Coregonus albula*	Vertebrate	12	4	4	4
Natterjack toad *Bufo calamita*	Vertebrate	15	8	8	8
Curl Bunting *Emberiza cirlus*	Vertebrate	14	7	7	7
Basking Shark *Cetorhinus maximus*	Vertebrate	21	36	36	36
Grey Partridge *Perdix perdix*	Vertebrate	20	37	37	37
Otter *Lutra lutra*	Vertebrate	19	38	38	38
Capercaillie *Tetrao urogallus*	Vertebrate	18	6	6	6

The results show a distinct change in the ranking from the COPY-efficiency. Without more variables it is difficult to know what to attribute these differences to. We know SFA is picking up inefficiency, but in this form of the model we cannot attribute the inefficiency to any specific variable or trait. The addition of more variables will allow the researcher to begin to explain why a species changes in relative ranking. The next step in this paper is to add what category or class the species in contained in. Three categories were established to begin to investigate species differences on the efficiency ranking; the categories were vertebrates, invertebrates, and plants. The same three SFA processes were used and the results regression output results are shown below.

Table 4

Regression Results for the Class Model

Independent Variables	Truncated SFA	Exponential SFA	Half Normal SFA
Constant			
Coefficient	0.4667804	0.4871853	.4685931
Std. error	(.7792959)	(.3123262)	(.9319111)
t-stat	0.60	1.56	0.50
PV_Cost			
Coefficient	1.28E-07	1.28E-07	1.28e-07
Std. error	(1.38e-07)	(1.38e-07)	(1.38e-07)
t-stat	0.93	0.93	0.93
Plant			
Coefficient	-0.1091768	-0.1091625	-.1091616
Std. error	(.3373359)	(.3373975)	(.3373391)
t-stat	-0.32	-0.32	-0.32
Vertebrate			
Coefficient	-0.0067441	-0.0067405	-.006739
Std. error	(.4843305)	(.4844166)	(.4843351)
t-stat	-0.01	-0.01	-0.01
Lambda	0.0008014	0.030094	.007668
$Sigma^2$	0.7267254	0.7264188	.7261946

This output again does not yield significant terms, but this is acceptable because the aim is to uncover inefficiency, not explain the production process.

Several main points from the regression outputs are that the coefficients match what economic theory suggests they should. The sign of the plant and vertebrate coefficients are negative, which says that these species will have lower predicted COPY rates relative to invertebrates. This matches what we find when we look at the data. We see that invertebrates tend to have the best response rates in population growth which matches the data. This shows invertebrates tend to have the highest COPY statistic and lowest COPY-efficiency score. Therefore, the model is correctly picking up the importance of the category of species. Distinctions and insights like this are what make SFA analysis beneficial. We also see that the cost of the program has a positive correlation to the COPY indicator. This statistic also matches what we would expect, that there is some correlation between spending more money and gaining more results. This information indicates there may be a need for a new method of judging efficiency, such as SFA, because a program that receives more money does no achieve necessarily better results. Previous chapters have discussed the importance of species traits and efficiencies of programs, but we do expect more money to yield a necessarily better COPY rate for an SAP. This is shown by similar species with similar funding yielding wildly different growth outputs. Expenditures are a necessary but not sufficient indicator of growth.

The outputs that include species classes also show similarities to the current method of COPY-efficiency, with a notable number of variations. This further supports the successful application of SFA. We expect that the current method of efficiency measure to yield a similar result, but ultimately some variation between COPY-efficiency and SFA is expected and desired. It is the changes in rankings that provide the interesting insights of SFA. The typical regression outputs, coefficients, and levels of significance have been shown, but it is the inefficiency ranking that is most valuable in SFA. The rankings of the COPY-efficiency and SFA, truncated normal, half normal and exponential distributions, are shown in the following table.

Table 5

Range Model SFA Rankings

Species Action Plan (Page 1)	Species Class	COPY-efficiency Ranking	Truncated Normal SFA Ranking	Exponential SFA Ranking	Half Normal SFA Ranking
A ground beetle *Bembidion argenteolum*	Invertebrate	21	25	25	25
A rove beetle *Stenus palposus*	Invertebrate	21	25	25	25
A weevil *Melanapion minimum*	Invertebrate	21	27	27	27
A weevil *Procas granulicollis*	Invertebrate	21	28	27	27
Pashford pot beetle *Cryptocephalus exiguus*	Invertebrate	21	29	28	28
Red alga *Anotrichium barbatum*	Invertebrate	21	18	18	18
Norfolk flapwort *Lophozia rutheana* *	Invertebrate	21	19	19	19
Jumping weevil *Rhynchaenus testaceus*	Invertebrate	21	30	30	30
A lichen *Calicium corynellum*	Invertebrate	8	16	16	16
A leaf beetle *Cryptocephalus nitidulus*	Invertebrate	9	11	11	11
6 spotted pot beetle *Cryptocephalus sexpunctatus*	Invertebrate	21	31	30	30
Marsh moth *Athetis pallustris*	Invertebrate	21	32	32	32
Straw belle *Aspitates gilvaria gilvaria*	Invertebrate	11	24	24	24
Bast bark beetle *Ernoporus tiliae*	Invertebrate	21	33	33	33
Leaf-rolling weevil *Byctiscus populi*	Invertebrate	5	14	14	14
Norwegian mugwort *Artemisia norvegica*	Invertebrate	21	20	20	20
Bog hoverfly *Eristalis cryptarum*	Invertebrate	1	1	1	1
Newman's lady fern *Athyrium flexile*	Invertebrate	21	21	20	20
Glutinous snail *Myxas glutinosa*	Invertebrate	21	34	34	34
Hazel pot beetle *Cryptocephalus coryli*	Invertebrate	7	12	13	13

Species Action Plan (Page 2)	Species Class	COPY-efficiency Ranking	Truncated Normal SFA Ranking	Exponential SFA Ranking	Half Normal SFA Ranking
A leaf beetle *Cryptocephalus primarius*	Invertebrate	2	15	15	15
Ramshorn snail *Anisus vorticulus*	Invertebrate	13	13	12	12
Narrow-mouthed whorl snail *Vertigo angustior*	Plant	6	5	5	5
Whorl snail *Vertigo geyeri*	Plant	3	3	3	3
Deptford pink *Dianthus armeria*	Plant	4	2	2	2
Fen orchid *Liparis loeselii* *	Plant	21	22	22	22
Yellow marsh saxifrage *Saxifraga hirculus*	Plant	10	9	8	8
Oblong Woodsia *Woodsia ilvensis*	Plant	21	23	23	23
Vendace *Coregonus albula*	Plant	12	4	4	4
Heath fritillary *Mellicta athalia*	Plant	16	17	17	17
Freshwater pearl mussel *Margaritifera margaritifera*	Plant	21	35	35	35
Large blue butterfly *Maculinea arion*	Vertebrate	17	10	10	10
Natterjack toad *Bufo calamita*	Vertebrate	15	8	9	9
Curl Bunting *Emberiza cirlus*	Vertebrate	14	7	7	7
Basking Shark *Cetorhinus maximus*	Vertebrate	21	36	37	37
Grey Partridge *Perdix perdix*	Vertebrate	20	37	36	36
Otter *Lutra lutra*	Vertebrate	19	38	38	38
Capercaillie *Tetrao urogallus*	Vertebrate	18	6	6	6

As we can see from the table, there have been significant differences between the COPY-efficiency measures to the SFA ranking. This variation shows that SFA has taken more into account when includes variation in species, beyond cost. Within the vertebrate category, capercaillies, curl buntings natterjack toads, and vendance, saw a relatively large increase in relative efficiency in ranking under the application of SFA. It is worth noting that the Otter, Basking shark, and Grey partridge, also vertebrates, became relatively less efficient in the SFA rankings. This change is because of the theoretical production maximum that SFA applied to these species. With previous analysis processes a non-uniform production maximum was not possible, which made it impossible to judge a species compared only to itself. The rankings provided by SFA are shown as the amount of inefficiency from their own production maximum.

Similar changes are seen in both invertebrates and plants. We see the leaf beetle (*Cryptocephalus primaries*) decrease in efficiency ranking and drop from 2nd to 15th. These changes reflect the actual efficiency of the program instead of lower cost species gaining absolute advantage, as in COPY-efficiency. The bog hoverfly is the most efficient in all rankings. This consistency suggests that not only is the bog hoverfly an excellent use of resources, but act as another indicator that SFA is accurately capturing inefficiency. The bog hoverfly acts as a logical check because it effective growth with a high COPY score and at a relatively low cost. At first glance we would expect this species to perform well in more rigorous statistical analysis. The bog hoverfly's good performance in SFA acts as a check to one result that is expected from the naked eye. We see many changes and variations in rankings, but there is also enough continued similarity to suggest that the variation captured has a strong theoretical background. Policy makers can look at these results and evaluate future funding decisions. It may be that a shift in funding to more efficient programs is merited, but another option is to explore the programs that have had success and apply those methods to new species. This will allow funds to be applied to species that are experiencing success, and also providing a system to explore what conservation methods work best. With SFA species traits are able to be accounted for, which will ultimately allow the actual efficiency of the program to be considered, rather than which species are biologically easiest to save.

A possible extension to this research will be presented now. As discussed in previous chapters, as more information is provided for species traits, we will even better be able to evaluate the efficiency of the program. Another system of rankings will now be introduced, where the SFA includes the relative size of the entire species habitats. This is an example of including more possible traits of each species; the range of habitat has been split into a category based on the percent of the United Kingdom the species inhabits. The three categories can be broken down to, local, regional, and the ultra regional or taking up the majority of the UK. This is done to help explore the effect of a species taking inhabiting a larger percent of the UK. It may make sense that as a species takes up more natural space, it may be relatively more expensive to save the species, or at the least that a dollar of expenditure may not go as far because the area of habitation is so large. Regression outputs indicate that the regional habitat is the easiest to save, which indicates if a species takes up large or small percent of the country conservation is more difficult. The regression output for the SFA including the percent of the country the entire species inhabits is shown in the following table.

Table 6

Regression Results for the Range Model

Independent Variables	Truncated Normal	Exponential	Half-Normal
Constant			
Coefficient	.2861871	3071767	.2884792
Std. error	(.5565032)	(.361904)	(.5569303)
t-stat	0.51	0.85	0.52
PV_Cost			
Coefficient	1.55e-07	1.55e-07	1.55e-07
Std. error	(1.39e-07)	(1.39e-07)	(1.39e-07)
t-stat	1.12	1.12	1.12
Plant			
Coefficient	-.1572546	-.1572558	-.1572546
Std. error	(.3383574)	(.3384174)	(.3383616)
t-stat	-0.46	-0.46	-0.46
Vertebrate			
Coefficient	-.1278136	-.127815	-.1278136
Std. error	(.49818)	(.4982649)	(.4981862)
t-stat	-0.26	-0.26	-0.26
Local			
Coefficient	.270276	.2702779	.270276
Std. error	(.3360294)	(.3360905)	(.3360336)
t-stat	0.80	0.80	0.80
Ultra Regional			
Coefficient	.3439625	.3439619	.3439625
Std. error	(.3586472)	(.3587108)	(.3586516)
t-stat	0.96	0.96	0.96
Lambda	.0005064	.0300525	.0076147
$Sigma^2$	.7064777	.7063781	.7061702

The coefficients above show that the regionalized pull COPY down more relative to local and ultra regional. This indicates that species in the regional category face the highest impediments to growth. This is an interesting result because it would be expected that as the range increases, the difficulty of saving the species becomes less potent. Instead, the coefficients show that it is relatively easier to increase COPY with a very small region or a very large region.

The final table will show the changes in efficiency rankings for the when truncated normal SFA is applied and also as more species variables are included in the regression. As the previous rankings tables have shown, there is almost complete homogeneity across all SFA methods. With this in mind, it will be beneficial to see how the rankings change as more control variables are added to the regression. The column headings will be described so that it is clear exactly what each column of rankings is showing. The COPY-efficiency column is ranks the SAPs based on the current methods of species conservation. The “SFA with no dummies” category represents the use of SFA with only the COPY value and the cost in the regression. The “SFA with Class Dummy” adds the class of species the program falls into. The categories for this paper were vertebrate, invertebrate, and plant. This allows us to investigate whether the class of the species affects the expected efficiency. This will help answer the question as to whether or not some species are biologically more difficult to save because of the type of species they are; this will help show that an SAP may be more efficient even thought the COPY-efficiency score is worse than another species. The final category adds the percent of the relative size of the entire species habitats as an example of including more possible traits each species has been split into a category based on the percent of the United Kingdom the species inhabits. The results are shown on the next page.

Table 7

All SFA Model Rankings Compared

Species Action Plan (Page 1)	Species Class	COPY-efficiency Ranking	SFA no Dummies	SFA Class Dummy	SFA Class and Range Dummy
A ground beetle *Bembidion argenteolum*	Invertebrate	21	19	25	30
A rove beetle *Stenus palposus*	Invertebrate	21	19	25	30
A weevil *Melanapion minimum*	Invertebrate	21	21	27	18
A weevil *Procas granulicollis*	Invertebrate	21	21	28	18
Pashford pot beetle *Cryptocephalus exiguus*	Invertebrate	21	23	29	32
Jumping weevil *Rhynchaenus testaceus*	Invertebrate	21	26	30	20
A leaf beetle *Cryptocephalus nitidulus*	Invertebrate	9	11	11	9
6 spotted pot beetle *Cryptocephalus sexpunctatus*	Invertebrate	21	26	31	33
Marsh moth *Athetis pallustris*	Invertebrate	21	28	32	21
Straw belle *Aspitates gilvaria gilvaria*	Invertebrate	11	18	24	29
Bast bark beetle *Ernoporus tiliae*	Invertebrate	21	29	33	22
Leaf-rolling weevil *Byctiscus populi*	Invertebrate	5	14	14	12
Bog hoverfly *Eristalis cryptarum*	Invertebrate	1	1	1	1
Glutinous snail *Myxas glutinosa*	Invertebrate	21	32	34	34
Hazel pot beetle *Cryptocephalus coryli*	Invertebrate	7	13	12	10
A leaf beetle *Cryptocephalus primarius*	Invertebrate	2	15	15	24
Ramshorn snail *Anisus vorticulus*	Invertebrate	13	12	13	13
Narrow-mouthed whorl snail *Vertigo angustior*	Invertebrate	6	5	5	7
Heath fritillary *Mellicta athalia*	Invertebrate	16	16	17	15
Freshwater pearl mussel *Margaritifera margaritifera*	Invertebrate	21	35	35	37
Large blue butterfly *Maculinea arion*	Invertebrate	17	10	10	14
A lichen *Calicium corynellum*	Plant	8	17	16	23

Species Action Plan (Page 2)	Species Class	COPY-efficiency Ranking	SFA no Dummies	SFA Class Dummy	SFA Class and Range Dummy
Red alga *Anotrichium barbatum*	Plant	21	24	18	25
Norwegian mugwort *Artemisia norvegica*	Plant	21	29	20	27
Newman's lady fern *Athyrium flexile*	Plant	21	29	21	27
Deptford pink *Dianthus armeria*	Plant	4	2	2	2
Fen orchid *Liparis loeselii* *	Plant	21	33	22	16
Yellow marsh saxifrage *Saxifraga hirculus*	Plant	10	9	9	11
Oblong Woodsia *Woodsia ilvensis*	Plant	21	34	23	17
Vendace *Coregonus albula*	Vertebrate	12	4	4	4
Natterjack toad *Bufo calamita*	Vertebrate	15	8	8	8
Curl Bunting *Emberiza cirlus*	Vertebrate	14	7	7	5
Basking Shark *Cetorhinus maximus*	Vertebrate	21	36	36	35
Grey Partridge *Perdix perdix*	Vertebrate	20	37	37	36
Otter *Lutra lutra*	Vertebrate	19	38	38	38
Capercaillie *Tetrao urogallus*	Vertebrate	18	6	6	6

This final graph shows the changes in the rankings as more species traits were introduced. Some species remained in a similar ranking, but many saw drastic changes. Some of these changes have been discussed throughout this chapter, but a side-by-side comparison shows the change in rankings as more traits are added. A discussion of several of the more dramatic changes in the rankings will help illustrate the effect of each different model. A weevil, *Procas granulicollis,* was a relatively inefficient SAP according to COPY-efficiency, but at the progression of SFA models includes more characteristics it becomes relatively more efficient. This is most clear with the introduction of the range model, because it is regional we find it was more efficient with that aspect controlled for. Similarly the pashford pot beetle has changes in the ranking, but with this species it becomes less efficient because the species is local. According to the coefficients the local and ultra local species are penalized for their relative advantage, thus leveling the playing field.

The straw belle is a relatively efficient species according to the COPY-efficiency but is less efficient in SFA. This is because the straw belle is an invertebrate and in the range model it is a local species. These factors contribute to make the straw belle a relatively less efficient species than in the COPY-efficiency rankings. The leaf beetle saw one of the more dramatic rankings changes, going from 2nd in the COPY-efficiency rankings to 24th in the full range model. This is again because it is an invertebrate and locally distributed. A lichen saw a similar change in ranking, but it is a plant, so the major change because of its local distribution. These factors are not enough to completely penalize a species that is efficient, with the best example being the bog hoverfly. The bog hoverfly is both an invertebrate and a locally distributed species. With these factors controlled for, it is still the most efficient SAP. Finally, the Capercaillie became drastically more efficient in SFA, from 18th in COPY-efficiency to 6th in all

SFA processes. This is most likely due to the fact that SFA does not automatically penalize expensive programs. Capercaillie had one of the highest COPY figures, but because it was also so expensive the rankings in COPY-efficiency suffered. SFA correctly accounted for the inefficiency and found even though the program was expensive, the resources were relatively well used.

There is evidence that many of these effects will be more pronounced with a larger data set. This scarcity of data is shown in the data section, with many of the COPY values are zero. It is not accurate to remove these observations because they are not zero in the sense of containing no information, but that the SAP saw zero or negative growth over the time of the program. The concern is that these zero values skew down the results more than just that particular SAP experiencing zero growth. This is yet another reason for governments to demand a more encompassing report and account of spending and output. Less than five percent of UK species are accounted for in this study, and this study is the largest use of COPY currently available. This lack of accountability creates a complete disconnect between funding and results based decisions. The concern is not intentional mishandling of funds, but an absence of empirical evidence in money allocation.

CONCLUSION

The application of Stochastic Frontier Analysis (SFA) in species conservation will provide a new method of ranking efficiencies of species action plans (SAPs). The results and discussion section showed how the use of SFA changes the way in which programs are evaluated, which has major implications for funding and management of SAPs. This ability to properly identify successful programs will allow more effective conservations and yield a higher benefit per dollar. The results of the SFA show a more inclusive measure of conservation, as well as the benefit of expanding research into incorporating more species biological traits.

With species conservation funding being extremely limited and more species being threatened, the efficiency of programs has become a much more necessary tool. The last decade has seen an increase in the study of conservation efficiency, but the field is continuing to establish new methods and searching for a universally accepted method. As funding has increased, a tool judging the efficiency has become a necessity. Many of the current methods of conservation biology have been adopted from public health economics. One of the most progressive techniques for measuring effectiveness has been the creation of Conservation Output Protection Year (COPY). This gives researchers a consistent indicator to measure the growth of a species across years. The indicator is consistent and reliable because it keeps the statistic in terms of the increase in population of an SAP. A conversion to like units, such as a currency measure, is not needed for measuring effectiveness.

Current research injects cost into this figure by multiplying COPY to get a COPY-efficiency measure. This figure fails to incorporate inherent biological differences between species, which makes a completely informed funding decision difficult. The COPY-efficiency measure can then be used to rank programs when an assumption of equal value is present. The equal value assumption makes unlike units comparable because the researchers have said that the value of all species is equal. SFA allows for these differences in value and funding to be accounted for, giving policy makers a more robust information set. The COPY-efficiency method also calculates efficiency rather than technical efficiency. SFA calculates technical efficiency which means it actually calculates whether or not the current output maximizes output while minimizing inputs. It essentially picks up how much, if any, more you could have created with the same set of inputs. This is in contrast to current notions of efficiency used in species conservation, which only gives an output per dollar. Output per dollar is not meaningful within a specific SAP, but only in comparison to another program. Technical efficiency comments on how much more output could have been created with the given inputs, which can then be compared across species.

The research presented in this paper has the opportunity to be expanded on. As more data is collected and the COPY measure becomes universal, the expansion of SFA will be possible. Many researchers have adopted COPY as one of the best effectiveness measures species population growth. Conservation laws and policies have been strongly established for 15 to 20 years, which means the effects are now being widely seen. It will be important for policy makers to specifically require SAPs to participate in surveys. This will help the pursuit of a universal and comprehensive application of an output measure, such as COPY. The statistics used in this study represent the largest collection of COPY statistics, and only 38 SAPS are represented, less than 5 percent of all UK SAPs. Stricter government requirements for participations will give a larger sample, and allow researchers to truly evaluate funding decisions. The increase in data will have strong positive implications for SFA analysis is conservation; the larger sample will yield a much more robust regression analysis. Also more species characteristics will be able to be incorporated, which will give an even better illustration of efficiency.

Research and collection of species traits will greatly aid the study of species conservation. As conservation biologists catalogue more information about species fertility/mortality, home range size, age to sexual maturity, and other traits, the traits can be incorporated into efficiency analysis. Current methods divide the cost and COPY statistics, give a non-species specific output. They believe is that this creates a completely objective method of conservation, when in fact it may put certain species at a disadvantage. Policy makers should have the information of whether an SAP is technically efficient relative to its own maximum, not only in comparison to another species, which often times has few biological similarities.

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APPENDIX

This section will introduce possible changes to the model that did not fit in the main body of the text. This section will show the basic ordinary least squares (OLS) and introduce the concept of a cost squared term. This creates the possibility of diminishing or increasing returns. As we will see the quadratic term does change the result dramatically, but with limited data it creates an issue of properly fitting the data.

The OLS results will be shown here for completeness. The results are very similar to those proposed by SFA. The difference, and reason for using SFA, is that OLS does not allow any method for capturing inefficiency. The sigma and lambda terms, that are required to judge efficiency, are not included in OLS. Therefore, it is worth showing the OLS outputs, but OLS ultimately is unable to capture the traits that make SFA ideal for use in species conservation. The regression output for the class model using OLS is shown below.

Table 8

Basic OLS Regression Output

Independent Variables	OLS
Constant	
Coefficient	.4634433
Std. error	(.1928521)
t-stat	2.40
PV_Cost	
Coefficient	1.28e-07
Std. error	(1.46e-07)
t-stat	0.88
Plant	
Coefficient	-.1091616
Std. error	(.5120331)
t-stat	-0.31
Vertebrate	
Coefficient	-.006739
Std. error	(.5120331)
t-stat	-0.01

When compared with table 4, we see that the results are indeed very similar. This is interesting, but without the lambda and sigma values OLS is unable to address relative inefficiencies.

The quadratic term does drastically change the results, and actually changes the most efficient species to the capercaillie. This is the first time in the analysis that the bog hoverfly is not the most efficient. As explained in the body of the text, the bog hoverfly is a species where efficiency is intuitively obvious. It had a high effectiveness measure and a low cost. We therefore expect that it would be a relatively efficient species. SFA failed to converge in the truncated normal distribution with the quadratic term. This is cause for alarm that perhaps the introduction of the term is negatively impacting the results. However, it is worth examining further because the results showed that vertebrates were much more relatively efficient. The results for the exponential and the half normal are very similar, so to best illustrate the change only the half normal distribution will be shown. The table will show the half normal with the quadratic term and the original half normal model. The regression output is shown as:

Table 9
Regression Results for the Half-Normal Class Model with Quadratic

Independent Variables	Half Normal SFA	Half Normal SFA w/ Quadratic
Constant		
Coefficient	.4685931	.5315278
Std. error	(.9319111)	(1.147013)
t-stat	0.50	0.46
PV_Cost		
Coefficient	1.28e-07	-4.64e-07
Std. error	(1.38e-07)	(4.57e-07)
t-stat	0.93	-1.02
PV_Cost^2		
Coefficient		7.56e-14
Std. error		5.58e^-14
t-stat		1.35
Plant		
Coefficient	-.1091616	-.1454893
Std. error	(.3373391)	(.3305548)
t-stat	-0.32	-0.44
Vertebrate		
Coefficient	-.006739	-.52263
Std. error	(.4843351)	(.6135279)
t-stat	-0.01	-0.85
Lambda	.007668	.0085639
$Sigma^2$	.7261946	.6926985

The vertebrate variable shows the largest change. The introduction of the quadratic has a huge impact on vertebrates, making them drastically more relatively efficient. The significant change is that the cost squared coefficient is now positive. This implies that as cost increase the effectiveness measure increases, or in general terms increasing returns to scale. The implications of increasing returns to scale will be discussed after the results table is presented. This relative increase in vertebrate efficiency is shown on the next table, which shows the rank of the species before and after the introduction of the quadratic term.

Table 10

Half-Normal SFA Model Compared with Quadratic

Species Action Plan (Page 1)	COPY-efficiency Ranking	Half-Normal SFA	Half-Normal SFA with a Quadratic
A ground beetle *Bembidion argenteolum*	21	25	37
A rove beetle *Stenus palposus*	21	25	37
A weevil *Melanapion minimum*	21	27	35
A weevil *Procas granulicollis*	21	27	35
Pashford pot beetle *Cryptocephalus exiguus*	21	29	34
Red alga *Anotrichium barbatum*	21	18	26
Norfolk flapwort *Lophozia rutheana* *	21	19	25
Jumping weevil *Rhynchaenus testaceus*	21	30	32
A lichen *Calicium corynellum*	8	16	19
A leaf beetle *Cryptocephalus nitidulus*	9	11	13
6 spotted pot beetle *Cryptocephalus sexpunctatus*	21	30	32
Marsh moth *Athetis pallustris*	21	32	31
Straw belle *Aspitates gilvaria gilvaria*	11	24	27
Bast bark beetle *Ernoporus tiliae*	21	33	30
Leaf-rolling weevil *Byctiscus populi*	5	14	15
Norwegian mugwort *Artemisia norvegica*	21	20	23
Bog hoverfly *Eristalis cryptarum*	1	1	2
Newman's lady fern *Athyrium flexile*	21	20	23
Glutinous snail *Myxas glutinosa*	21	34	29
Hazel pot beetle *Cryptocephalus coryli*	7	13	14
A leaf beetle *Cryptocephalus primarius*	2	15	20
Ramshorn snail *Anisus vorticulus*	13	12	12
Narrow-mouthed whorl snail *Vertigo angustior*	6	5	6
Whorl snail *Vertigo geyeri*	3	3	4
Deptford pink *Dianthus armeria*	4	2	3

Species Action Plan (Page 2)	COPY-efficiency Ranking	Half-Normal SFA	Half-Normal SFA with a Quadratic
Fen orchid *Liparis loeselii* *	21	22	22
Yellow marsh saxifrage *Saxifraga hirculus*	10	8	10
Oblong Woodsia *Woodsia ilvensis*	21	23	21
Vendace *Coregonus albula*	12	4	11
Heath fritillary *Mellicta athalia*	16	17	17
Freshwater pearl mussel *Margaritifera margaritifera*	21	35	16
Large blue butterfly *Maculinea arion*	17	10	5
Natterjack toad *Bufo calamita*	15	9	9
Curl Bunting *Emberiza cirlus*	14	7	8
Basking Shark *Cetorhinus maximus*	21	37	28
Grey Partridge *Perdix perdix*	20	36	18
Otter *Lutra lutra*	19	38	7
Capercaillie *Tetrao urogallus*	18	6	1

The change in the vertebrate coefficient changed the rankings and made it so that vertebrates are relatively more efficient. This result changes the interpretation, but because of lack of data this transformation cannot be confirmed. Most notably the otter goes from last place in the relative ranking to 7th. Similarly the grey partridge moves to 18th from 36th in the half-normal SFA. The basking shark and curl bunting are relatively unchanged. It may be that the quadratic term takes away most of the penalty for an SAP being extremely expensive. The quadratic term actually predicts that as more money is spent relative efficiency increases. This could have major implication for funding allocation. It may also indicate that there is a minimum amount of money that is needed for a species to see growth. As shown in table 1, there is a large variation in funding, from 970£ to 7,000,000£. The quadratic term suggests that generally the more expensive programs are relatively more efficient, or at the least the penalty for being high cost is thoroughly removed. It may be that adding a quadratic makes the analysis more rigorous, but considering one of the distributions failed to converge the analysis is not the strongest of those proposed in this thesis. As research continues in this approach a quadratic term should be considered, but without richer data the risks of inclusion outweigh the rewards.