Team Control Number

1924813

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2019

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Summary Sheet

Our team was hired to tackle one of the greatest problems remaining in the 21st century: *how do we prevent the "tragedy of the commons?"* Specifically, our task was to "create an ecological services valuation model to understand the true economic costs of land use projects when ecosystem services (ES) are considered." We discovered that answering this question is key for governments to rent land to entities for land-use projects at a price necessary to preserve the value of ES owned by all.**

Our team began by exploring the axioms of rational choice, the fundamental philosophical underpinnings of value, and the economic systems which best support our theory of value. We settled on Bayesian Decision Theory, well-being-based Utilitarianism, and Georgism, respectively. Our model was created in the context of satisfying the requirements of these three philosophies.

We then explored preexisting models for ES valuation and extracted their best elements. We ultimately settled on a model which prices land-use projects' impact on ES in terms of dollars necessary to artificially recreate the ES expected to be destroyed. Where destroyed ES may not easily be recreated, we calculate the expected Quality Adjusted Life Years prevented from occurring, and convert these into dollars at a median, non-industry rate.

Our final model is as follows:

$$V = t(E - r + \in)$$

where $\boldsymbol{V}$ is the value of the total estimated economic cost of the land-use project over its life span in years, $\boldsymbol{t}$ is the expected life span of the land-use project in years, $\boldsymbol{E}$ is the sum of economic benefit gained from all ES per year, $\boldsymbol{r}$ is the total revaluation loss of all assets (based on periodic impairment tests) per year, and $\in$ is the unaccounted economic benefit of other ES not considered in our model. $\boldsymbol{E}$ is further defined as:

$$E = E_P + E_R + E_C$$

where $\boldsymbol{E_P}$, $\boldsymbol{E_R}$, and $\boldsymbol{E_C}$ are the sum of the economic benefit gained from provisioning, regulating, and cultural ES, respectively. These are each defined as:

$$E_P = F + G \qquad E_R = W + A \qquad E_C = T$$

where $\boldsymbol{F}$ represents Food and Fiber, $\boldsymbol{G}$ represents Genetic Resources, $\boldsymbol{W}$ represents Water Quality, $\boldsymbol{A}$ represents Air Quality, and $\boldsymbol{T}$ represents Eco-Tourism. The method for calculating these is outlined in our report.

We demonstrated the application of our model for a hypothetical 3-acre housing project in Redding, California expected to last 75 years and a 200-acre, amusement park project in Valdosta, Georgia expected to last 150 years. Our model yielded the true ES costs of these projects as $143,612 and $1,825,764, respectively. Further, we discuss powerful ways evaluators can estimate probabilities and utilities themselves, such as utilizing *prediction markets* and *Fermi Estimation*.

Much of the beauty of the global ecosystem lies in its diversity; however, this necessitates a way for such a model to be tailored to any number of vastly unique micro-ecosystems. Our model accounts for this by creating a process for the model's users to create new variables or subtract from the existing variables. In addition, the process creates a way for the model to be reassessed and changed over time. Ultimately, this allows planners and managers to create tax structures that account for the effect that land-use projects will have on the commons, both paying back the damage done to what is owned by all sentient beings and disincentivizing projects that would cause large scale environmental degradation.

Ecological Services Valuation Model: Understanding the True Cost of Land-Use Projects

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Contents

1 Introduction

Our team was hired to create an ecological services (ES) valuation model to understand the true economic costs of land-use projects when ES are considered.

In our pursuit of creating a model, we began by researching the philosophical underpinnings of value. We decided that well-being, based off conscious-subjective experiences, is the only good which is intrinsically valuable. While we maintain a degree of moral uncertainty on this matter, we ultimately decided to base our valuation of ecosystem services from their expected impact on well-being of conscious creatures, most especially humans.

We then explored the economic systems that best support our value-theory, and settled on Georgism, an economic philosophy which asserts that, while individuals ought to own the fruits of their own labor, natural resources are a public good [1]. Then, we researched the possible frameworks we could use to price ecosystem services, and determined the price should *reflect the cost of artificially replacing ES.* In other words, the value of an ES depends on the price to replace its services. For services that are irreplaceable, we propose a method of converting lost environmental services into Quality-Adjusted Life Years (QALYs), which may then converting into dollars based off the rate of producing QALYs.

We explored preexisting models for pricing the ES affected by land-use projects, and found several highly-developed, but difficult to apply models. To solve for this, we sought to create a model which balances accurate valuation with ease of applicability, while still maintaining our values of maximizing well-being. Thus, we designed a general model with only the most applicable variables.

2 Background

2.1 The Threat Facing the commons

Despite the long history of valuing select portions of nature economically, there seems to be a new quality to current approaches. [2] This new quality is based on an increasingly clear observation: there is real economic cost to over-exploiting ecosystems. Worse, this cost is not just limited to oneself and one's property, but to everyone as we live intimately connected in a global biosphere. Further, this implies that we will need to increase administration of the commons. A 'commons' is any resource that belongs to all sentient beings [3]. For this end, we need an open-source model that rationally prices the commons. Such a model must take into account the relative necessity of each plot of land capable of being exploited to protect humanities long term goals.

2.2 The Need to Price the Commons

The motivation for creating an ES valuation model is twofold. First, the mode produces a tangible metric that allows the complex concept of ES to be easily understood. Second, the model provides a way to hold respective entities accountable. To achieve these desired outcomes, we discussed accounting principles and frameworks that encourage greater accountability for and transparency of a land-use project's economic cost. We also explore the possible implications of our model, including land-use tax disincentives, and include recommendations for administrators who choose to use our model.

2.3 Definitions

2.3.1 Ecosystem

"An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit. Humans are an integral part of ecosystems" [6].

2.3.2 Ecosystem Services (ES)

"Ecosystem services are the benefits people obtain from ecosystems. These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services that provide recreational, aesthetic, and spiritual benefits*; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling. (See Figure A.) The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services." [6]

2.3.3 Biodiversity

"Biodiversity is the variability among living organisms. It includes diversity within and among species and diversity within and among ecosystems. Biodiversity is the source of many ecosystem goods, such as food and genetic resources, and changes in biodiversity can influence the supply of ecosystem services.” [6].

2.3.4 Value

“Value” can be something as intangible as the social satisfaction of belonging to a community. “While “value” has many non-monetary connotations (as proponents of economic valuation of nature are quick to point out), a monetary value, a price, is what matters for economic valuation” [4]

A common way economists price value is contingent valuation, where value is determined through surveys where participants state their preferences and willingness to pay for certain outcomes, such as the preservation of an environmental feature [7].

2.3.5 Quality Adjusted Life Years

Part of our model is based on Quality Adjusted Life Years (QALYs), a useful health economics metric that combines length of life with quality of experience. “One QALY is equal to 1 year of life in perfect health” [8]. Our paper will not go into detail on the various methods of calculating QALYs, but we will use the median non-industry threshold price of a QALY $9,500 observed in one study [8]. For instance, if a land-use project is thought to prevent 20 QALYs from occuring over its lifecycle through various predictable Nth-order effects, and one QALY is priced at $9,500, then the true cost of the land-use project should include the $195,000 in damage to human well-being and life expectancy.

2.3.6 Well-Being

“Human well-being is assumed to have multiple constituents, including the basic material for a good life, such as secure and adequate livelihoods, enough food at all times, shelter, clothing, and access to goods; health, including feeling well and having a healthy physical environment, such as clean air and access to clean water; good social relations, including social cohesion, mutual respect, and the ability to help others and provide for children; security, including secure access to natural and other resources, personal safety, and security from natural and human-made disasters; and freedom of choice and action, including the opportunity to achieve what an individual values doing and being. Freedom of choice and action is influenced by other constituents of well-being (as well as by other factors, notably education) and is also a precondition for achieving other components of well-being, particularly with respect to equity and fairness.” [6] In our report, the philosophical underpinnings for **the valuation of ES rests on its influence on human well-being**, although we admit that the lives of non-human conscious creatures are intrinsically valuable as well.

2.4 Assumptions

2.4.1 Ecosystems are Valuable as a Means to an End

We make the assumption that ES are not intrinsically valuable, but because of their impact upon sentient well-being. This is our most essential assumption. The assumption is based on a utilitarian and biocentrist ethical framework that the only intrinsic good is the subjective experience of all sentient life [10][11]. Therefore, in creating a model to find the price of a land-use project's effect on ES, the cost will be measured in how environmental degradation will effect surrounding being's subjective experience. Due to the utilitarian nature of this framework, life is not viewed as being infinitely valuable which allows effects to be monetarily quantified. In addition, we maintain the traditional biocentrist view that all life is not equally valuable due to the varying levels of consciousness (i.e. the subjective experience of a beetle is less valuable then a human's)[11].

2.4.2 Land-Use Projects Must Be Time Based

Land-use Projects must be time-bound in order for our model to work. If this were not the case, our model would have to account for the expected impact of ES on well-being over a nearly infinite time-horizon.

2.4.3 Bayesian Decision Theory is the Framework for Rational Choice

Bayesian Decision Theory is the proper statistical and theoretic approach to quantifying the value of ES. In more concrete terms, we believe we ought to make decisions based off *expected utility* (the products of utility and probability) rather than just known effects. For example, we may know for certain a building a highway through an everglade will kill at least 1000 fish, but our best predictions may suggest that there is a 20% chance that 10,000 fish may be killed. The expected dis-utility then is at least 2000 fish will be killed, and this is the appropriate number to factor into our model.

2.4.4 The Default of Nature is not Optimal

Changing the landscape is not inherently bad. Assuming otherwise presumes the natural state of nature happens to be optimal. This is clearly not the case. We can do better than the impersonal forces of evolution that optimize for survivability and reproduction rather than well-being. Given that land-use projects are theoretically permissible, we have a need to price ecosystem services that are expected to ultimately be affected by land-use projects.

2.4.5 Utility Independence of Land-Use Projects

While the actual non-environmental function and positive utility of land-use projects is extremely important, we do not consider this for our model. It is up to administrators to price the value of a hospital to be built. We consider it our job to price the ES. Therefore, our model is independent of the land-use project's utility.

3 Past Ecosystem Evaluation Model

3.1 The Value of a Statistical Life (VSL) Model

Today, most research institutions and high-income countries base their ES models on the VSL concept– the quantification of a group's willingness to pay (WTP) to decrease the likelihoods of dying. To do so, an estimate of how much the average person would willingly pay to decrease the probability of dying by a marginal amount. The model then quantifies the VSL as being the average WTP of a population multiplied by the population size [14][15].

$$VSL = WTP * Population \tag{3.1}$$

The total economic cost of environmental degradation is then calculated by multiplying the VSL by the lives lost to its effects.

$$EconomicCost = VSL * LivesLosttoEnvironmentalDegradation \tag{3.2}$$

We see this status quo way of modeling the monetary cost of environmental degradation as being problematic for two reasons:

3.1.1 Variable Inaccuracy

Accuracy for this model depends upon the ability of humans to accurately gauge the value of decreasing the probability of mortality. This is problematic because in practice, humans tend to be wildly insensitive to the implications of such complex concepts.

3.1.2 Non-Inclusive Cost

Even if the proper way to evaluate economic cost is to base models purely off the impact that environmental degradation has on human populations, the VSL model does a not fully evaluate all such costs. By focusing purely on loss of life, the impact environmental degradation has on living population's quality of life is lost.

A land-use project that does not result in any deaths can still affect the quality of life of surrounding populations. For example, a land-use project has the sole environmental impact of contaminating a municipality's water supply. The municipality is able to import water from a neighboring city's supply. In such a scenario, the VSL model would evaluate the environmental cost as being zero dollars, as no one was killed by the project. However, this project came at a cost to the surrounding population. It can be, thereby, inferred that the VSL model could use significant improvements to accurately evaluating human cost.

4 Modeling Ecosystem Degradation

4.1 Accounting for Liabilities

Our model's general foundation is influenced by an Ecosystem Health and Sustainability report by Sue Ogilvy at the Fenner School of Environment and Society [17]. Throughout Ogilvy's report, the challenges associated with accounting for liabilities related to ecosystem degradation are addressed with several aspects.

4.1.1 Ecosystem Accounting

The first step in accounting for liabilities (where liabilities reflect the lost economic value of an ecosystem) is quantifying ecosystem information with standard economic accounts for production, income, capital, and net worth. To do so, evaluators must spatially delineate different ecosystem types within a broader area of interest, assess its condition, and categorize each asset's service. The asset is broken down into three specific classifications of services [6], as follows:

- *Provisioning* (food, fresh water, fiber, biochemicals, and genetic resources)
- *Regulating* (climate regulation, disease regulation, water regulation, water purification, and pollination)
- *Cultural* (spiritual and religious, recreation, aesthetic, educational, cultural heritage)

Lastly, evaluators must assess the relative value of the various benefits offered from the ES. This value will then be used when assigning total economic cost of a land-use project. Note that *supporting services* (those that are necessary for the production of all other ES, such as soil formation, nutrient cycling, and primary production) were not listed because "[these services] differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people" [6].

4.1.2 Treatment of Cultivated Biological Resources

All provisioning assets that are bearer plants (i.e. grows produce) are subjected to periodic impairment tests. This ensures that the quality of individual assets are accounted for over a period of time, which ultimately holds the entity accountable for the lasting effects of their land-use project. The reduction in a given asset's value must be communicated as an outflow of economic benefit, which is labeled as revaluation loss and must be factored into the final valuation model.

4.1.3 Treatment of Operating Leases

The lease of an ecosystem is considered an operating lease and not a financial lease. An operating lease is an asset that either depreciates over time or is matched with a liability. In other words, the entity makes a contract that allows for the use of an asset but does not convey rights of ownership of the asset [18]. Essentially, entities may be obliged to restore certain ES if necessary.

5 Our Algorithm

5.1 Our Hypothetical Scenarios

To facilitate understanding of our ES valuation algorithm, we have constructed two scenarios under which we will demonstrate our algorithm in action:

Project 1 (Small Scale Land-Use Project): Lake Redding Estates, located in Redding, CA, is planning on expanding their housing development by building a new cul-de-sac (going West off of Harland Dr.) consisting of ten new houses. The land-use project is expected to cost three million dollars without accounting for environmental considerations and would take place over three acres of land. For the purposes of this report, we will assume that this project will last seventy-five years.

Project 2 (Large Scale Land-Use Project): Six Flags is planning on opening a new amusement park location in Valdosta, GA. The land-use project is expected to cost three hundred million dollars without accounting for environmental considerations, and would take place over two-hundred acres of land (including parking) [19]. The expected life span of the park is one hundred fifty years, based on the oldest operating amusement park (172 years). This area of this project is defined by the coordinates: (30.865744284443828,-83.18809971213341),(30.87546684656096,-83.18345922719931), and (30.873419357875783,-83.168538852084).

5.2 Provisioning Ecosystem Services

5.2.1 Food and Fiber (F)

One of the primary provisioning ES that our model considers is the available combination of food and fiber from a given ecosystem. This variable serves an important role in our model because humans take advantage of many production-related services from plants, which ultimately results in a quantifiable economic value. These variables are represented as the NPP (Net Primary Production: the rate at which all the plants in an ecosystem produce net useful chemical energy [20]), which is measured as the mass of carbon per unit area per year for a given ecosystem ($\frac{g*C}{m^2*yr}$). This ES can then be integrated into our model with its associated mean NPP [20]. To convert the mean NPP to a monetary value, a shadow price for NPP will be used [21]. The shadow price (the estimated price of a good or service for which no market price exists) is calculated as \$1996$/million\,kg\,carbon/year$.

Project 1: The ecosystem type in Lake Redding Estates is categorized as Oak Woodlands by the California Environment Information Sources [22]. The mean NPP for woodlands is 700 $\frac{g*C}{m^2*yr}$. The calculated shadow price at three acres totals to \$16.96 per year, or \$1,272 over 75 years.

Project 2: The projected Six Flags location in Valdosta, GA, is categorized as coastal plains [23], and is located in a woodland ecosystem. The mean NPP for the woodlands is 700 $\frac{g*C}{m^2*yr}$. The calculated shadow price at two hundred acres totals to \$1130.85 per year, or \$169,627.50 over 150 years.

5.2.2 Genetic Resources (*G*)

This ES is defined as the genes and genetic information used for animal and plant breeding and biotechnology [6]. The value of individual species is proportional to the role that they play in the ecosystem in addition to their potential use by humans for research purposes (e.g. potential future use in developing pharmaceuticals). One way of quantifying this value involves considering the probability of humanity ever creating useful pharmaceuticals from the given species, as well as the value of this theoretical pharmaceutical. A simpler way to calculate the value of a genetic resource that could become critically endangered through a land-use project is to determine which is lower: 1) the immediate cost to sequence and store its DNA in addition to the future cost to clone it back into existence for research purposes, or 2) the cost to keep said endangered species alive in another ecosystem.

Project 1: Our research does not indicate their being endangered species in the three acre area to be converted into houses.

Project 2: Our research does not indicate their being endangered species in the two hundred acre area to be converted.

5.3 Regulating Ecosystem Services

5.3.1 Water Quality (*W*)

The cost that land-use projects have have on Water Quality will be defined in terms of decreased arable land– land in which water can infiltrate and seep through. This is because, when rainwater cannot infiltrate the ground, runoff to nearby water sources is increased [24]. Water accumulates pollution as it runs across the ground. To calculate the amount of water that will fall on the land-projects non-arable land per year, the locations average rainfall (R), in inches per square foot per year, must be converted into gallons (1 inch per square foot per year equating to point six gallons). This will then be multiplied by the total area of non-arable square feet (N) of the land-use project through dimensional analysis. This is then multiplied by the cost of purifying a gallon of water in the United States($.0003), something that, if done, would maintain the welfare of sentient beings [26].

$$W = R * N * .0018 \tag{5.1}$$

Project 1: Using Redding's average rainfall, and assuming that forty percent of the land will remain arable results in the price of $814.10 per year, or $61,057.50 over 75 years [27].

Project 2: Using Valdosta's average rainfall, and assuming that fifty percent of the land will remain arable results in the price of $3,817 per year, or $572,550 over 150 years [28].

5.3.2 Air Quality (A)

Ecosystems contribute useful chemicals and extract harmful chemicals from the atmosphere, influencing air quality. The economic cost of this ecosystem service can be quantified and integrated into our model in terms of dollars per ton of carbon that the environment could have removed from the atmosphere. According to NC State University: College of Agriculture and Life Sciences, an average aged tree can absorb approximately 48 pounds of carbon dioxide per year and can sequester 1 ton of carbon after 40 years [29]. As of 2015, the cost of offsetting carbon dioxide is $3.30 per tonne [30]. The economic cost of air quality can then be calculated by multiplying the amount of carbon dioxide that an ecosystem absorbs, specifically by trees, and the cost of offsetting carbon dioxide.

Project 1: According to the University of Maryland, the average number of trees per acre in woodlands is 500 [31]. Lake Redding Estates, CA, was classified as woodlands under the provisioning section for Food and Fiber, so we assume that a metric of 500 trees per acre in this potential neighborhood is fair estimate. The total economic cost of clearing out three acres of land totals to $107.77 per year, or $8,082.75 over 75 years.

Project 2: Since the location in Valdosta, GA, was also classified as woodlands, we are also assuming that the average number of trees throughout the projected Six Flags location is 500 trees per acre. Thus, the total economic cost of clearing out two hundred acres of land totals to $7,184.91 per year, or $1,077,736.50 over 150 years.

5.4 Cultural Ecosystem Services

5.4.1 Eco-Tourism (T)

Since the value of ecosystem belongs to everyone, we can deduce that everyone has a claim to the utility of enjoying and spending time in an ecosystem. To the degree in which a land-use project is expected to destroy this public good, we believe this cost has a place in our model. There are two approaches to calculating this cost: 1) consider past eco-tourism expenditures as revealed preferences 2) calculate the expected future QALYs lost by land-use projects and convert this into the cost to produce the same amount of QALYs. The latter approach can be modeled as:

$$T = P * \frac{A_m}{60 * 24 * 365} * W_f * Q \tag{5.2}$$

where T represents the value of eco-tourism, P represents the expected number of people per year to visit an ecosystem should a land-use project not be built, A_m is the average number of minutes each person spends there per year, W_f is the *well-being factor* (expected relative quality of a minute), and Q the cost of a QALY.

Project 1: This is not an area especially prone to eco-tourism, so our team estimates: P to be 50 (primarily people from the neighborhood), A_m to be 720 minutes per year (based off an estimation of twelve 1 hour outings), Q factor of 1.5 (someone would equally prefer to spend 2 hours there than 3 hours of average living), and a cost of a QALY to be $9,500 [9]. Thus, the estimated economic cost totals to $976 per year, or $73,200 over 75 years.

Project 2: As the land is in a rural area and does not appear to have hiking trails, the estimated economic cost totals to \$39 per year, or \$5,850 over 150 years.

5.5 Further Variables ($\in$)

This list of variables is non-exhaustive. Just as each variable has to be applied in a somewhat different manor to every individual case, as was seen in their application to Project 1 and Project 2, as each case is different. While we broadly see these variables as being the most applicable and important factors to consider when evaluating the environmental cost of land-use projects, we acknowledge that there are instances where some might not be necessary or an important factor not included. For instance, a land-use project may take place in a barren desert making consideration of the provisioning variables unnecessary. In another instance, there could be wildlife that a certain religious group considers sacred. It is ultimately up to those who use our model to decide what is applicable to their area, and if they find an area-specific variable that must be considered, they may reference our framework for variable creation.

5.6 ES Valuation Model

The final ecological services valuation model is composed of broader terms that all share the same units (USD\$). This section will clarify the composition of each term through various levels of depth. At the most broad level, the final model is as follows:

$$V = t(E - r + \in)$$

where V is the total estimated economic cost of the land-use project over its life span in years, t is the expected life span of the land-use project in years, E is the sum of economic benefit gained from all ES per year, r is the total revaluation loss of all assets (based on periodic impairment tests) per year, and $\in$ is the unaccounted economic benefit of other ES not considered by our individual model per year. The variable E can be examined more closely by defining the ES category:

$$E = E_P + E_R + E_C$$

where E_P, E_R, and E_C are the sum of the economic benefit gained from provisioning, regulating, and cultural ES, respectively. At the most in-depth level of our model, each ES category is divided into individual components:

$$E_P = F + G \qquad E_R = W + A \qquad E_C = T$$

where F represents Food and Fiber, G represents Genetic Resources, W represents Water Quality, A represents Air Quality, and T represents Eco-Tourism.

5.7 Project Results

Although our ES valuation algorithm is applied accurately to the two constructed scenarios (i.e. Project 1 and Project 2), the resulting economic cost of each project includes a certain amount of variability and error. Note that there was no estimated economic cost for Genetic Resources G, which has the potential to drastically affect the total economic cost of each project. The results of the two projects are as follows:

Project 1: $V = \$143,612.25$

Project 2: $V = \$1,825,764$

The results of these two projects provide a general insight into the potential economic costs of small and large scale land-use projects when ES are considered. Two of the most influential factors appear to be the size of the land-use project and the type of ecosystem where the project is located. The land-use project's negative impact on Air Quality A and Water Quality W ultimately depend on the ecosystem type, suggesting that planners and managers can be strategic when deciding on a location for their project.

5.8 Sensitivity Analysis

As our model is primarily composed of seven variables added or subtracted together, and there are reliable methods of calculating these variables, it is unlikely that different evaluators will yield wildly different results. The variable most capable of influencing cost, *time*, is also relatively easy to get right by looking at past data. Further, tax structures may be created which are flexible under variable-length land-use projects.

5.9 Limitations of Our Model

Our model does not fully encompass exogenous factors that alter the condition of ecological services, such as climate change, invasive species, or wild fires. This is due to the fact that attempting to factor such unpredictable and complex events into our model would result in an unacceptable amount of variance.

Specifically, we excluded factoring in *ornamental factors*, *pollination*, *regulation of human diseases*, *storm protection* into our model. These variables, while important, are difficult to calculate for most small and large scale land-use projects. Should they be able to be calculated, however, our model, as a cost-function, allows them to be added.

6 Counterarguments

6.1 Critiques of Valuation Based on Restitution

For many cases, the cost to destroy an ES, which is a public good, can be best thought of as equivalent to the cost to add that service. For example, since it costs \$3.33 to remove one ton of carbon from the atmosphere [30], we ought to tax companies for adding one ton so that we can make up for the cost. However, a fair critique of this valuation method is that once certain ecosystem problems become bad enough, we reach a point that not only do we need to pay \$3.33 to reduce one ton of carbon, but we also need to prevent 1 ton of carbon from being placed into the atmosphere; we can't afford any more damage. The honest way to think about this, however, is that the cost of taxes should no longer be a one to one ratio, but a greater ratio. In other words, there has to be a tax-price that can be placed upon a plot of land so that even the most staunch environmentalists would hope that a corporation would buy the rights to exploit such plot of land. This is because this money could reliably produce more environmental services than are destroyed.

6.2 Intractability of Probability and Utility Estimates

Since our model is an algorithm which requires evaluators to determine the values of many variables themselves, it may seem that calculating the variables is sometimes computationally intractable. This is not the case for the practical application of our model, as even when little data is available, we have powerful tools for calculating both probabilities and utilities at our disposal:

6.2.1 Estimating Probabilities: Prediction Markets

For many land-use projects, we have lots of repetitive past data which allows us to extrapolate the probability distribution of possible outcomes of similar future land-use projects. For others, we have very little or no data, and are unable to predict future outcomes well with traditional statistical models. Based off the work of economist Robin Hanson, we have another tool to estimate the probabilities of various outcomes of land-use projects: prediction markets. These are markets whose primary purpose is to aggregate information rather than to entertain or hedge risk [32]. For the largest, most potentially impactful land-use projects, ES evaluators have the option of establishing a prediction market to pool the information and expertise of many environmental experts. They merely need to define an array of specific possible outcomes that they are curious about in an information market, and, once betting has taken place over several days, they may utilize the market prices to infer the probabilities of different outcomes of land-use projects. These probabilities may then be used in their model.

6.2.2 Fermi Estimation

As our model is a general algorithm for evaluators to use in a variety of different ecosystems, evaluators have no choice but to make personal estimations for several of the cost variables. For some variables, depending on the availability of data and viability of collecting new data, *Fermi estimation* is the only practical means to accomplish this. This involves making justified guesses about quantities and their variance, tends to be surprisingly accurate and within an order of magnitude.

7 Implications of our Model

7.1 A More Representative Cost

The economic Shareholder Value Theory shows precisely why a company or organization would be interested in disregarding the environmental cost of their actions. The theory states that corporate managers should act exclusively in the economic interests of shareholders [35]. Therefore, if businesses and economic managers can take advantage of "the commons" to achieve their a desired business objective (such as building more housing or a new amusement park) at the lowest cost possible, it would behoove them to do so. This can most easily be seen throughout the early history of American industrialization in which businesses, to give one of numerous possible examples, would dump waste into public waters without cost or repercussion. The U.S. Congress passed a series of legislation in the 1960's and 1970's to curtail such exploitation of the commons, including the Environmental Protection Agency [36].

In order to curtail this innate nature of commercial managers to utilize ecological services that belong to all people, we suggest that municipal, state, and national governments use this model to create tax policies that would account for the degradation of public environmental services. The effect of this would be two-fold. First, governments would be able to utilize the tax-revenue to replace what was degraded, therefore maintaining the welfare of their citizenry. Second, this more accurate representation of cost would create an incentive structure that would encourage economic entities to have less negative environmental impacts. For example, say a certain business was planning a land-use project and could complete it in two different ways. One way would cost \$2,000 without a tax, but would do a modeled \$500 dollars in environmental damage. The other would cost \$2,200 without a tax, but would only do \$200 dollars of damage. If there were no tax in place, the company's managers would be incentivised to choose the first land-use project. However, if the tax were in place, they would be incentivised to choose the second, less damaging option. This new incentive structure, therefore, works within economic theory to preemptively decrease environmental damage.

7.2 After Estimated Life Spans

As the concept is grounded in Georgism, policy makers may find it necessary for land-use projects to be reevaluated if they exceed their estimated life spans. As can be seen in the discussion of variables, the costs of environmental degradation are not always immediate but rather accumulate with time. This means that, in order for the greatest accuracy in environmental cost, policy-makers may find re-assessment essential. We suggest, however, that project managers should be made aware of such conditions.

7.3 Evaluators Need to be Utilitarian

Ultimately, their is an incentive for land-trustees to profit from the economic exploitation of their land. As the cost-output produced by our model represents the negative externalities of land-use projects– in other words, the destruction of value owned by the public– evaluators must be impartial utilitarians who believe in the validity of our model. Thus, our team recommends that that evaluators have no financial stake in the valuation process.

8 Conclusion

In our report, we provided a clear framework, influenced by utilitarianism and biocentrism, for how it is possible to construct a finite value of environmental services, and, therefore, how it is possible to determine the environmental cost of land use development projects. This was done in a two-fold manner. First, by determining what it would cost to completely replace the ES that the land use project would degrade. Second, if it is not possible to replace what was degraded, mainly relating to cultural ES, metrics for the cost on sentient experience were determined.

We then showed how our model was developed, and applied it to both a small and large-scale land-use project. While our existing variables account for the majority of the cost of environmental degradation, the real effectiveness of our model lies in its elasticity. Much of the beauty of the global ecosystem lies in its diversity; however, this necessitates a way for such a model to be tailored to any number of vastly unique micro-ecosystems. Our model accounts for this by creating a process for the model's users to create new variables or subtract from the existing variables. In addition, the process creates a way for the model to be reassessed and changed over time. Ultimately, this allows planners and managers to create tax structures that account for the effect that land-use projects will have on the commons, both paying back the damage done to what is owned by all sentient beings and disincentivizing projects that would cause large scale environmental degradation.

9 References

[1] Hooper, C. L. (n.d.). Henry George. Retrieved January 28, 2019, from http://www.econlib.org/library/Enc/bios/George.html

[2] Kill, J. (2015, September). *Economic Valuation and Payment for Environmental Services Recognizing Nature's Value or Pricing Nature's Destruction?* [PDF]. Heinrich Böll Foundation.

[3] Hardin, G. (1968). The Tragedy of the Commons. *Science, 162(3859)*, 1243-1248. doi:10.1126/science.162.3859.1243

[4] Harmon, L. J. (2012). An Inordinate Fondness for Eukaryotic Diversity. *PLoS Biology*, 10(8). doi:10.1371/journal.pbio.1001382

[5] Kates, G. (2016, August 11). Environmental Crime: The Prosecution Gap. Retrieved January 28, 2019, from https://thecrimereport.org/2014/07/14/2014-07-environmental-crime-the-prosecution-gap/

[6] Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-Being, Synthesis* [PDF]. Washington D.C.: Island Press.

[7] Cummings, R. G., Brookshire, D. S., Schulze, W. D. (1986). *Valuing Environmental Goods: A State of the Arts Assessment of the Contingent Valuation Method* (B ed., Vol. I, Rep.). Washington D.C.: The Institute for Policy Research.

[8] National Institute for Health and Care Excellence. (n.d.). Glossary. Retrieved January 28, 2019, from https://www.nice.org.uk/glossary?letter=q

[9] Azimi NA, Welch HG. *The effectiveness of cost-effectiveness analysis in containing costs.* J. Gen Intern Med. 1998;13:664–9.

[10] Mill, John Stuart (2014). *Utilitarianism.* Cambridge University Press.

[11] Robin Attfield. (2012). Biocentrism and Artificial Life. *Evironmental Values, 21, 83-94.*

[12] Hughes, C. (2018, November 22). Tyler Cowen's Stubborn Attachments-A Review. Retrieved January 28, 2019, from https://quillette.com/2018/11/21/stubborn-attachments-a-review/

[13] Current World Population. (n.d.). Retrieved January 28, 2019, from http://www.worldometers.info/world-population/

[14] Norgaard, R. (April 2010). Ecosystem Services: From Eye-Opening Metaphor to Complexity Blinder. *Ecological Economics, 69, 6, 1219-1227.*

[15]The Cost of Air Pollution: Strengthening the Economic Case for Action. (2016). *The World Bank and Institute for Health Metrics and Evaluation University of Washington, Seattle.*

[16] Desvousges, W. Johnson, R. Dunford, R. Boyle, K. J. Hudson, S. and Wilson K. N. (1992). *Measuring non-use damages using contingent valuation: experimental evaluation accuracy.* Research Triangle Institute Monograph 92-1.

[17] Sue Ogilvy, Roger Burritt, Dionne Walsh, Carl Obst, Peter Meadows, Peter Muradzikwa, Mark Eigenraam. (2018). Accounting for liabilities related to ecosystem degradation. Ecosystem Health and Sustainability , Vol 4, Iss 11, Pp 261-276 (2018),

(11), 261. Retrieved from https://doi.org/10.1080/20964129.2018.1544837

[18] Kenton, W. (2018, December 13). Operating Lease. Retrieved from https://www.investopedia.com/terms/o/operatinglease.asp

[19] Platt, E. (2012, July 23). 7 Fascinating Facts About Six Flags. Retrieved from https://www.businessinsider.com/six-flags-facts-2012-7

[20] Stiling, P. D. (1998). Ecology: Theories and Applications. Upper Saddle River, NJ: Prentice Hall.

[21] Valuing ecosystem services: A shadow price for net primary production. (2007, May 03). Retrieved from https://www.sciencedirect.com/science/article/pii/S092180090700198X

[22] Research Guides: California Environment Information Sources: Natural Communities and Habitats. (n.d.). Retrieved from http://libguides.humboldt.edu/c.php?g=303807&p=2028631

[23] Clausen, E. (2017, September 13). Georgia's Ecosystems. Retrieved from https://www.peachdish.com/blog/WblBiR8AAEsOjnfY/georgias-ecosystems

[24] The Links Between land-use and Groundwater. (August 2014). *Global Water Partnership.* Perspectives Paper.

[25]Our Water Supply. (n.d.). *City of Redding Public Works.* Retreived January 27, 2019, https://www.cityofredding.org/departments/public-works/public-works-utilities/water-utility/water-supply.

[26]Rogers, Callie. (May 2008). Economic Costs of Conventional Surface-Water Treatment: A Case Study of the McAllen Northwest Facility.

[27]Redding Weather Averages. (n.d.). *U.S. Climate Data.* Retrieved January 27, 2019, from https://www.usclimatedata.com/climate/redding/california/united-states/usca0922.

[28]Valdosta Weather Averages. (n.d.). *U.S. Climate Data.* Retrieved January 27, 2019, from https://www.usclimatedata.com/climate/valdosta/georgia/united-states/usga1253.

[29] NC State University: College of Agriculture and Life Sciences. (n.d.). Tree Facts. Retrieved from https://projects.ncsu.edu/project/treesofstrength/treefact.html

[30] Hamrick, K Goldstein, A. (2016, May). Raising Ambition: State of the Voluntary Carbon Markets 2016. *Ecosystem Marketplace.* Retrieved January 25, 2019, from https://www.forest-trends.org/publications/raising-ambition/.

[31] Stewart, N., Dawson, N. (2013). Forest Thinning: A Landowner's Tool for Healthy Woods. Retrieved from http://extension.umd.edu/

[32] Hanson, R. (2003). Combinatorial Information Market Design. *Information Systems Frontiers*, 5(1), 107-119. Retrieved January 28, 2019, from http://mason.gmu.edu/~rhanson/combobet.pdf

[33] Hanson, R. (1996, June 12). Idea Futures. Retrieved January 28, 2019, from http://econfaculty.gmu.edu/hanson/ideafutures.html

[34] Muehlhauser, L. (2013, April 11). Fermi Estimates. Retrieved January 28, 2019, from https://www.lesswrong.com/posts/PsEppdvgRisz5xAHG/fermi-estimates

[35]Loderer, C., Roth, L., Waelchli, U. Joerg. (2010). Shareholder Value: Principles, Declarations, and Actions. *Financial Management, 39, 5-32.*

[36]EPA History. (n.d.). *The Environmental Protection Agency.* Retrieved January 27, 2019, from `https://www.epa.gov/history`.