11-2013

# An Environmental Economic Analysis of Social Discounting

Kyle Stoddard Runyan Young

## Recommended Citation

Young, Kyle Stoddard Runyan, "An Environmental Economic Analysis of Social Discounting" (2013). *Master's Capstone Theses.* Paper 12.

# Thesis Submission

**From:** jason siniscalchi
**Sent:** Thursday, November 21, 2013 8:40 AM
**To:** ThesisCapstoneSubmission
**Cc:** Pollio, Carol
**Subject:** Capstone Thesis submission

---

This capstone has been approved by Dr. Jason Siniscalchi for submission, review, and publication by the Online Library. (The thesis advisor should note whether the thesis is accepted generally or accepted with distinction)

Author's Name: __Kyle Stoddard Runyan Young___________________________

Title: _Environmental Economic Analysis of Social Discounting

Professor: __Dr. Jason M. Siniscalchi__________________________________________

Second Reader, if required: ______________________________

Program: __EVSP699 K001 Sum 13

Pass with Distinction:  This had two boxes one with "yes" and one with "no"
**YES** NO

Keywords/Descriptive Terms:
intertemporal discounting sustainability economics social ecological intergenerational equality

# AN ENVIRONMENTAL ECONOMIC ANALYSIS OF SOCIAL DISCOUNTING

A Master Thesis

Submitted to the Faculty

of

American Public University

by

Kyle Stoddard Runyan Young

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

February 2014

American Public University

Charles Town, WV

# DEDICATION

I dedicate this thesis to my loving wife and daughter. Only through their loving support, understanding, and patience was this work possible.

## ACKNOWLEDGMENTS

I wish to thank all of my professors through my course of study in environmental policy and management for their support, guidance, encouragement, and enlightening educational instruction. First I would like to express my gratitude to Dr. Jason Siniscalchi for helping me ensure comprehensive and accurate data gathering and statistical analysis in this project. Dr. Maureen Sevigny was instrumental in helping me recognize the inherent flaws in intertemporal discounting from an environmental perspective and formulate my views on how discounting might be corrected to better protect our natural resources. Dr. Frederic Bouchet's instruction in global economics also greatly expanded my understanding of the interrelationship between neoclassical economics and resource consumption, providing me with a robust intellectual fascination and resource for this paper's topic. Dr. Linda Allen's teachings on the moral and social 'face' of our ecological decisions served as a constant motivator for environmental and social action in my work. In doing so, Dr. Allen helped solidify my decision to undertake a project that, in addition to addressing a knowledge gap in social discounting, might also provide a practical means to improve the conservation of our invaluable natural resources while working in concert with the seemingly immobile, existing framework of neoclassical economics. Congruent with that end, this project aims to examine and propose a positive improvement for resource sustainability, but without the need to move the proverbial 'iceberg' of our contemporary economic system. Saving the very best for last, my wife, Sara, and my daughter, Addison, have both motivated me to be a voice for the future through my graduate school course work, catalyzing the central issue in this paper – our valuation and protection of natural resources through social intertemporal discounting.

My coursework in environmental policy and management at American Public University has been extremely thought provoking.  It has grown my ability to evaluate the implications of human actions on Earth’s life-sustaining capabilities.  More importantly, my coursework with American Public University (APU) has matured my understanding of the human obligation to protect Earth’s resources for future generations as well as the inherent challenges that come with this powerful and important duty.

# ABSTRACT OF THE THESIS

## AN ENVIRONMENTAL ECONOMIC ANALYSIS OF SOCIAL DISCOUNTING

by

Kyle Stoddard Runyan Young

American Public University System, November 10, 2013

Charles Town, West Virginia

Professor Jason Siniscalchi, Thesis Professor

By examining social discounting through a neoclassical economic lens, this study analyzes the ecological and resource impact, and the empirical flaws of contemporary discounting methods. This study then conducts a neoclassical analysis of economic data relevant to social discounting, including inflation rates, other-than-inflationary resource cost increases, supply/scarcity-derived cost increases, substitutability of money for resources, and intergenerational valuations. The shortcomings of contemporary discounting are quantifiably resolved using correction factors, which are derived from the aforementioned data analyses. The correction factors are incorporated into a modified social discounting equation. Ultimately, neoclassical economic principles are examined for suitability in improving ecological sustainability by reducing social discount rates. The data analyzed in this study indicate that contemporary discount rates are overvalued, leading to the undervaluation of future ecological benefits for present day cost-benefit decisions. Additionally, the modified social discounting equation yields a successful means of improving social discount rates towards ecological sustainability, through a descriptive, neoclassical economic approach.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

# I. INTRODUCTION

*“We do not inherit the earth from our ancestors; we borrow it from our children.”*

- *Anonymous*

The world’s human population is operating within a system of resource extraction and consumption that is severely ecologically constrained and becoming progressively more so with time. Bourucke et al. (2013) estimated the current sustainable capacity of Earth’s bioproductive land to be 1.8 global hectares (gha) per person. Given contemporary resource extraction and consumption rates, humanity’s global ecological footprint is well in excess of this, at approximately 2.6 gha per person, or 17.6 billion total ghas (Borucke et al., 2013). As a result, the world’s population is faced with an untenable ecological and resource situation, requiring 1.5 Earths to meet the requirements of ecological sustainability (Venuto, 2012). If the United States’ (U.S.) average resource consumption rate were extrapolated to Earth's population of seven billion, protecting sustainability would require more than five Earths (Global Footprint Network, 2012; Venuto, 2012). Such excessive resource consumption rates degrade nature’s reproductive capabilities and beget an ever-decreasing supply of natural resources for future generations. Additionally the demand for Earth’s resources is also increasing due, in large part, to world population growth, coupled with developing economies’ quests for economic growth and their acceleratory resource and energy consumption.

The Earth’s bioproductive capabilities are being severely encroached upon from both sides of the economic spectrum – supply and demand. Moreover, demand-side stressors further decrease Earth’s natural resource supply and productivity through increased consumption, thereby creating a negative feedback loop. Already, wetlands worldwide have been reduced by

50% since 1900, 58% of coral reefs are at risk, and the majority of the world's fishery stocks are categorized as over-fished (Stuip, Baker, & Oosterberg, 2002). Global sustainability, or the ability to protect against the degradation of Earth's current carrying capacity and promote the availability of equal or commensurate resources for future generations, is at stake.

This global sustainability problem begets an important resource management challenge for current and future generations. As the study of the allocation of resources amongst competing ends, economics will play an important role in addressing this challenge. The world's economic practices can either embolden this pattern of acceleratory resource extraction, or conversely, they can mitigate and even reverse this unsustainable trend. (Daly & Farley, 2004; Pugel, 2012).

The economics of resource management functions on the interrelationship of three variables: Quantity and time (both as inputs and independent variables), and value or cost (the dependent output variable). Neoclassical economics, the economic system that prevails in today's international marketplace, attempts to maximize total benefits and efficiencies based on present-day production quantities. This optimization function often occurs in the absence of consideration for the second independent variable of time (Daly & Farley, 2004). If present or short-term benefits *can* be compared directly to present costs in a neoclassical analysis, the result is, unfortunately, a maximization of present net benefits (or optimal efficiency) without consideration of future generations.

Neoclassical economics, however, does not entirely ignore the variable of time. When encountering a decision requiring the comparison of future benefits to current costs, economists commonly use a method known as intertemporal discounting (commonly referred to as ‘discounting’). This enables the restructuring and quantification of future benefits as an equivalent present value, essentially enabling an ‘apples-to-apples comparison’ between future benefits and present costs (Daly & Farley, 2004; Keohane & Olmstead, 2007). All business investment decisions are, in fact, merely the automatic application of discounting in order to determine the allocation of resources between present and future generations (Daly & Farley, 2004). Given the increasing challenges of sustainability and resource depletion, environmental degradation, and other time-sensitive ecological functions, the field of environmental economics (a subset of neoclassical economics) also uses discounting to compare the time-dependent costs and benefits of an environmental action. This process of discounting, in theory, promotes the preservation of neoclassical economic goals (maximizing net benefits) across *both* spatial (e.g. quantity as input variable) *and* temporal scales by permitting time as an additional input variable. However, unlike the individual-determined and investment-based discount rates, the *social discount rate* associated with such environmental actions should reflect “society’s collective ethical judgment, as opposed to an individualistic judgment, such as the market rate of interest” (Daly & Farley, 2004, p. 273). Unfortunately, current discounting methods commonly fail to account for several quantifiable economic, ecological, and social realities, including inflation, resource scarcities, and intergenerational valuations. The result is that intertemporal discounting tends to undervalue future ecological benefits, supporting present-day economic actions (or inactions) that undermine sustainability, ecological protection, resource preservation, and sustainability.

This study examines the relationship between intertemporal discounting and ecological resource consumption and sustainability, and analyzes the ecological failings of contemporary discounting methods used in the United States in the field of environmental economics. Additionally, this study proposes a modification to intertemporal social discounting methods in the United States to account for objective, time-based economic criteria as well as subjective valuations of future generations, and to improve the accuracy of social discount rates. Data on inflation trends, increasing resource costs due to resource scarcities and other market dynamics, substitutability of money for resources, and valuation of future generations is examined and incorporated into the proposed modified social discounting equation. The modified social discounting equation is then analyzed to determine if it achieves the anticipated results of revaluing future resources (in present day equivalent values) to better-motivate present-day environmental action, thereby combating accelerating resource extraction and promoting ecological conservationism and sustainability.

## III. LITERATURE REVIEW

Through an examination of the existing academic literature on social discounting for the past quarter century, including economic text books, peer reviewed science and economic journals from 1989 through 2013, and governmental publications, this study first conducts an overview of discounting, including discussions of individual versus social discounting and of discounting's application to environmental economics. This study then reviews several specific examples of the use of discounting for social and environmental actions in the U.S., internationally, and for concerted global efforts. Next, this literary examination addresses the preexisting academic awareness of and dissension concerning social discounting as it applies to ecological sustainability and intergenerational equity. Finally, existing recommendations for improving social discounting rates are reviewed.

Ultimately, the literary examination will indicate the lack of deliberation given to several factors in correcting social discount rates. In doing so, it will emphasize the importance of this study in answering the underlying hypothesis that social discounting methods contribute to the degradation of natural resources and global sustainability by failing to or inadequately accounting for: (1) Inflation (due to monetary and fiscal policies and domestic production); (2) resource and service cost increases due to other market dynamics; (3) resource cost increases due specifically to resource scarcities; (4) monetary versus resource substitutability; and (5) intergenerational valuations.

### *Discounting – An Overview*

Economics is the quantified study of resource allocation. In neoclassical economics – the prevailing economic framework in the United States and today’s global, free market system – the market supply-demand of individual consumers and suppliers determine the monetary ‘worth’ of resources by seeking equilibrium of marginal supply and marginal demand (Pugel, 2012). Additionally, the neoclassical economic system seeks to maximize net monetary benefit (the cumulative total of consumer and supplier surplus) in the marketplace through resource allocations. In neoclassical economics, the end goal of maximizing efficiencies has traditionally accounted for the entire spatial spectrum (everybody participating in the market on both supply and demand sides) within the global marketplace (The Daily Bell, 2012). Though this maximization of benefits often occurs across strictly spatial scales as an integrated function of marginal resource cost and quantity, it can also occur simultaneously across both spatial and temporal scales (The Daily Bell, 2012; Pugel, 2012). Neoclassical economics, by definition, does not concern itself with *how* resources are distributed amongst spatial (geographic) and temporal scales (e.g. whether they are distributed evenly, per se). Thus the economic goal of maximizing net benefits can and should incorporate the consideration of temporal scales whenever market decisions have a temporal component and such a time-dependant consideration is feasible.

Intertemporal discounting is the method by which this variable of time is accounted for in economics. Discounting enables future values, whether benefits or costs, to be adjusted into an equivalent present value for the purpose of conducting cost-benefit comparisons and economic decision-making. By accounting for the independent variable of time, discounting allows for the efficient allocation of resources for economic decisions that affect the future, thereby promoting the neoclassical principle of maximum net benefits across both spatial and temporal scales (Daly & Farley, 2004).

### *Definition of Terms*

For clarity, the following terms are defined:

‘Intertemporal discounting’ is “the process of valuing the future [in terms of present-day dollars] less than the present” (Daly & Farley, 2004, p. 271). For environmental economic purposes, this is the process of converting “all of the benefits and costs of a potential environmental policy, no matter when in time they occur, into their dollar value *today*…” and is used to conduct a cost-benefit analysis for actions and effects occurring at different times

(Keohane & Olmstead, 2007, p. 28).

‘Ecological sustainability’ is using the earth’s natural resources in a manner that does not compromise the earth’s ability to meet the needs of future generations. For the purpose of this study and from a perspective of resource consumption, ‘improving sustainability’ refers to any action that reduces contemporary resource consumption, whether for finite or renewable resources, and/or increases the preservation of resources for future use.

‘Future generations’ refers to different people, separated by time (commonly, and for the purposes of this study, accepted as a 20 year separation). The apportioning of resources across generations is known as ‘intertemporal distribution’ and is not to be confused with ‘intertemporal allocation’, which “is the apportionment of resources across different stages in the lifetimes of basically the same set of people” (Daly & Farley, 2004, p. 276).

‘Individual discount rates’ refer to the discount rates automatically determined by the marketplace (and commonly used for most discounting calculations) through individual business investment decisions.

‘Social discount rates’ refer to calculated discount rates that reflect “society’s collective ethical judgment, as opposed to an individualistic judgment, such as the market rate of interest” (Daly & Farley, 2004, p. 273).

### *Individual versus Social Discounting*

Individual discount rates are the rates determined based on individual consumer decisions on the marketplace. These are analogous to the free market interest rates established to support the monetary and resource investment decisions of consumers. These are normally motivated by a theory known as the ‘pure time rate of preference’, which describes the rationale that individual market decisions reflect a preference to hold resources today, at a greater total lifetime cost, over waiting for adequate financial means to purchase the resource in the future for a reduced cost (normally the resource’s ‘face value’) (Daly & Farley, 2004; Heal, 2005). Simply put, market interest rates are individual discount rates that reflect the preference (or relative demand) for resources *today*, versus at a prescribed (e.g. loan termination period) time in the *future*. If someone purchases a $200,000 home at a 30-year fixed interest rate (or individual discount rate) of 7%, that decision reflects their individual, economic assessment (or opinion) that the future worth of the house will be $1.5 million at time t = 30, according to the interest and discount equation, $FV = PV(1+r)^t$. Moreover, the market’s standard interest rate (7% in this example) reflects individuals’ – as an aggregate whole in the marketplace – relative demand for resources *now* versus resources in the *future*. Again, in this example, the individual values having possession of the resource *now* by a factor of nearly 7.6 over having it 30 years in the future. The term ‘intertemporal allocation’, or the “apportionment of resources across different stages in the lifetimes of basically the same set of people (the same generation)”, reflects the economic and resource dynamics of individual discount rates (Daly & Farley, 2004, p. 276).

Social discount rates, on the other hand, reflect “society’s collective ethical judgment” and are used to conduct cost-benefit analyses of environmental and social decisions or projects by calculating the equivalent present value of future resources (Daly & Farley, 2004, p. 273). Examples of such projects include the regulating or abatement of greenhouse gas emissions, the conversion of a protected forest into industrial timberland, and the nonrenewable siphoning of water from a wetland for agricultural development (Keohane & Olmstead, 2007). In contradiction to people's individualistic valuation of present day ownership due to their 'pure time rate of preference', many economists contend that social discounting rates should be lower than individual discount rates in order to account for society's collective ethical valuation of future generations and preference for the conservation of natural resources (Daly & Farley, 2004; Heal, 2005).

This study does not contend the prevalence of high individual discount rates. Such high interest rates are actually advantageous to the environment, as high individual discount and interest rates tend to slow economic activity, decrease "the demand for natural resource inputs" and motivate land preservation over land development (Krautkraemer, 2005, p. 38). Therefore, high individual discount rates (based predominantly on market interest rates) should prevail for socially and environmentally discrete business and investment decisions, in order to promote ecological sustainability. Conversely, however, and as Daly & Farley (2004) asserted, "higher [social] discount rates increase the intensity and rate of exploitation and are thus bad for the environment" (p. 272). Therefore, social discount rates should be modified to promote ecological sustainability. This study will conduct a modification of social discount rates using prevailing neoclassical principles and will examine whether such modifications yield an ecological sustainability improvement (time-dependent reduction) to the social discount rate.

### *Discounting and the Environment*

As a derivative of neoclassical economics, the field of environmental economics aims to optimize the efficiency of environmental actions. In doing so, environmental economics weighs costs and benefits across both spatial and temporal scales to determine the point where net benefit is maximized (e.g. where marginal benefit, or the quantity-based derivative of total benefit, is equal to marginal cost, or the quantity-based derivative of total cost) (Keohane & Olmstead, 2007). Most environmental actions hold a significant, and often protracted, time component to them due to a variety of time-delay factors – political, economic, industrial, and environmental. As just one example, the ratification of the Montreal Protocol in 1987 by 24 countries to abate and resolve ozone deterioration yielded the stabilization of ozone depletion by 1998, and is forecasted to return Antarctic ozone to healthy, pre-1980 levels by 2075 (U.S. Environmental Protection Agency [EPA], 2013a). Due to the significant role that the variable time plays in any environmental action, discounting is an essential component to environmental cost-benefit analyses (EPA, 2013a).

Discounting allows us to calculate the present-value (PV) of a future benefit or cost (FV), normalizing the analysis for temporal deltas and enabling an ‘apples-to-apples’ comparison across temporal scales. Per the discounting equation, $PV=\sum FV/(1+r)^t$, an equivalent present value (PV) is determined from a forecasted future net benefit or value (FV), and then compared against the cost of action that *would* beget the future environmental benefit to determine whether such action’s benefit (PV) outweighs its costs – e.g. whether the action is economically ‘efficient’ (Keohane & Olmstead, 2007).

The ability for discounting to accurately represent societal and economic realities and values is dependent on the social discounting rate (r) used in the aforementioned equation. One commonly used value for social discounting in the United States is the investment market’s average interest rate, making the social discount rate equal to the individual discount rate and signifying that the opportunity cost of paying *now* to achieve a future benefit, FV, at time, t, is the projected financial return if that money was *otherwise* invested at the market's interest rate (Arrow et al., 2013). With any positive discounting rate (r), equivalent present values trend asymptotically towards a minimum of zero as time increases (see Figure 1). Additionally, if FV gains are foreseeable immediately, the PV (equal to $\sum FV*(1+r)^t$ for each year) is summed for each subsequent year of future value benefits, yielding an equivalent present value that trends asymptotically towards a maximum as t increases (also depicted in Figure 1). Thus, per common discounting methods, after a certain time, t, future benefits (e.g. of an environmental action or resource extraction abeyance) yield negligible or counterproductive gains due to the discount rate. Moreover, the time at which future values become counterproductive (PV < current cost necessary to achieve FV) decreases with an increase in the discounting rate, r. Discounting using high, market-derived interest rates tends to favor environmental actions with short-term benefits due to the fact that discounting yields substantially smaller present values for longer-term benefits (Arrow et al., 2013; Keohane & Olmstead, 2007).

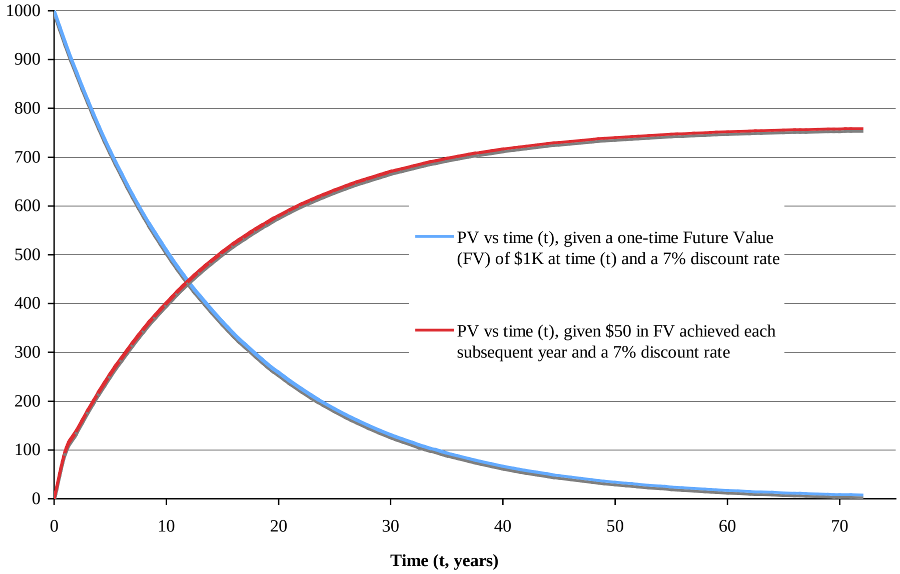

**Figure 1. Present Value (PV) vs. time (t)**

In the field of environmental economics, discounting is critically important to sustainability and the management of Earth's resources. As discussed earlier, sustainability is the ability to meet present day needs without compromising the needs of future generations (Randolph & Masters, 2008). By its very definition, sustainability requires the explicit comparison of future costs and benefits with those of the present. Consequently, the variable of time, quantitatively addressed through the process of discounting, plays an inescapable role in ecological sustainability. This, however, was not always the case.

The idea that time need *not* be considered in economic analyses – that the 'invisible hand' of classical and neoclassical economics will automatically ensure the future is better off – was accepted as conventional wisdom in many economic circles ever since the landmark economic works of Adam Smith (author of *The Wealth of Nations* and commonly recognized as the one of the pioneers of classical economics) (Carmody, 2012). The evidence used to support such claims include the rapidly (exponentially) increasing per-capita Gross Domestic Product (GDP), wealth, and associated living standards experienced since the early 1900s (Randolph & Masters, 2008). Additionally, as Harrison (2010) discusses, it has also been widely argued that technological improvements will compensate for the loss of nonrenewable and over-harvested renewable resources, providing a safe economic buffer for future generations against natural resource degradation.

These claims have been heavily countermanded in recent years. The assumption of increased per-capita wealth has been contended on the grounds that negative externalities associated with society's excessive consumption are making the world poorer (Daly & Farley, 2004). Additionally, in the face of global resource extraction rates that have far exceeded

Earth’s biocapacity and risk diminishing its bioproductivity rates, it is widely accepted that no scale of technological advancements can supplant the massive loss of natural resources and/or the loss of any single resource with a low substitutability threshold (Borucke et al., 2013; Carmody, 2012). Technology may continue to help humans optimize natural resource extraction rates, but it will never negate humans’ need for natural resources. Due to the realities of resource loss irreversibility and lack of substitutability, some economists even argue for complete “constancy of natural capital” to achieve sustainability goals (Beltratti, Chichilnisky, & Heal, 1993). Contrary to the previous school of thought, these new understandings of natural resources emphasized the importance of the time variable and intertemporal discounting – both for achieving ecological sustainability and maximizing net benefits (both spatially *and* temporally).

With respect to sustainable resource management, discounting is an important factor in determining optimal extraction methods for both finite and renewable resources, as well as for determining how to proceed with environmental protection or pollution abatement efforts. For finite resources, the rate of extraction for maximum profit is determined using Hotelling’s rule, which states that the rate of optimum extraction is where the resource’s annual value increase is equal to the market-based interest rate (Keohane & Olmstead, 2007). The net benefit of extracting the resource in the future (vice today) is discounted at the market interest rate to give an equivalent present value, which can then be added to today’s net benefit to yield a cumulative net benefit equation. The quantity of maximum net benefit (where marginal benefit equals marginal cost, or where the first derivative of this cumulative net benefit equation equals zero) is the point of maximum efficiency (Keohane & Olmstead, 2007).

A very similar type of analysis is conducted when determining the optimal time to harvest a renewable resource such as a forest. The optimum time of harvest (or quantity for extraction) is that point at which the resource is gaining value at a rate equal to that of the discount rate, r. If the resource is growing (gaining value) faster than this discount rate, then it is beneficial to wait to extract that resource. Conversely, if the resource is growing or reproducing slower than this discount rate, it is beneficial to extract now, as more benefit will be garnered on the financial and social yields of the extracted resource than from the resource's future yield based on its growth or reproduction (Keohane & Olmstead, 2007). This inverse ecological relationship between investment interest rates and discount rates leads Marks (2011) to determine that one cannot adjust market rates with the strict intent to achieve intergenerational equity. In short, discount rates matter in environmental economics. Moreover, the lower the (social) discount rate, the greater the impetus on conserving the resource for future extraction and future generations. Refer to Appendix A for a normative examination of prescriptive (theoretical) social discount rates, r' = 5%, 1%, and -2%, and their implications on equivalent present values (PV). As depicted in Figure A (in Appendix A), the lower the social discount rate, the higher the equivalent present value, and therefore the better any ecological or resource conservation action will fare in a present-day cost-benefit analysis using intertemporal discounting. Additionally, negative social discount rates yield present values that are *greater* than the forecasted future benefit of any present-day action, motivating maximum conservation-based decision making for future generations, but risking deprivation of resources for current generations. Thus, from a prescriptive perspective, a 'balanced' social discount rate is necessary to promote intergenerational equity.

This study examines the feasibility of reducing social discount rates for use with any socially/environmentally and temporally sensitive resource decisions (whether Keynesian/governmental or via regulated private enterprise), while simultaneously maintaining high free market-derived individual discount rates in order to mitigate resource pressures and improve ecological sustainability. This study proposes the modification of social discount rates by applying objective, quantifiable correction factors to existing *individual* discount rates. Such social discount rates should then be applied to corporate and Keynesian (e.g. governmental policies) decisions with considerable and temporally sensitive social and environmental implications. This study uses prevailing neoclassical economic principles and economically derived data to conduct this examination by mathematically accounting for important economic factors and then *adjusting* the free market individual discount rate accordingly to calculate a social discount rate that more accurately reflects society's empirical and objective valuation of future resources.

### *Examples of Discounting for Social and Environmental Actions*

The United States implements two overarching discount methods when considering intertemporal cost-benefit analyses (EPA, 2007). Though the EPA recommends a discount rate of zero for any action involving intergenerational benefits, the actual rates used for an Environmental Impact Analysis (EAI) are 7% (the investment interest-based discount rate) when analyzing the economic impact, and 3% (the consumption discount rate, which accounts for decreasing marginal utility and inflation) when conducting the social benefit-cost analysis (EPA, 2007). The U.S. Office of Management and Budget (OMB) follows suit, requiring a two-step analysis and comparison for intergenerational projects, using the 7% discount rate and testing at the 2 to 3% consumption rate (Harrison, 2010; Jeuland, 2010). The World Bank, in conducting cost-benefit analyses for the international projects it funds, uses a discount rate of 10% (Chutubtim, 2001). Most noteworthy is Jeuland's (2010) recognition that, despite economists arguing for social discount rates below 4% for large and ecologically-sensitive projects (such as dam installations), "many international development banks and government planning agencies responsible for project appraisal can be found using rates of 7 to 12% or more" (p. 185).

Discounting has been applied worldwide to projects that yield time-sensitive ecological effects. The rates and results of discounting measures, however, are highly variable. In 1989, a study was initiated by Costanza, Farber, & Maxwell (1989) to determine the present day value of wetlands for Louisiana wetland ecosystem management purposes. The study used a discount rate range of 3 to 8%, yielding a wetland valuation range of $2,429 to $6,400 per acre (Costanza et al., 1989). As applied to the Louisiana wetlands, the present-day value of the annual loss of wetlands varied tremendously from $77 million to $544 million; the discount rate played the most significant role of any factor on the value variance (Costanza et al., 1989). In another wetland example, the Merja Zerga Lagoon – "a wetland of 7,000 ha [hectares], located on the Atlantic coast of Morocco" – was evaluated in a pilot study to determine the wetland's total valuation (Stuip et al., 2002, p. 4). A discount rate of 6% was chosen for the study, devaluing/discounting the wetlands from greater than $100 million over a 50-year period to a present day value of only $33 million, and from greater than $200 million over a 100-year period to a present day value of just over $35 million (Stuip et al., 2002).

The use of discounting has been applied to energy cost-benefit analyses as well. In an examination of the net present value (NPV) of a hydropower dam project on the Blue Nile in

Ethiopia, a 2% discount rate returned a NPV of $9.5 to $33 billion (depending on river runoff), whereas a 6% discount rate yielded a net present benefit from $0.8 to 7.7 billion. Again, the perceived present-day ‘success’, or value, of the project is highly dependent on the chosen discount rate… which, in this study, was highly dependent on the estimated economic growth and stability of the region and the resultant marginal utility rates (higher assumed economic growth and stability yield greater wealth and reduced marginal utility, resulting in a higher social discount rate and lower NPV). Another example of how varying discount rates play a pivotal role in a project’s success is in the development of new power plants. The NPV of nuclear power plant production exceeds that of coal and natural gas technologies at a 5% discount rate (giving it a high equivalent present value for the lifecycle benefits of the plant and thus a positive NPV) (Keppler, 2010). However, nuclear power cannot out-compete the relatively low startup costs of coal and natural gas when a 10% discount rate is used (Keppler, 2010)

r = 5%: NPVnuclear = high present value – moderate start-up = high positive NPV
NPVcoal = moderate present value – low start-up cost = low positive NPV
r = 10%: NPVnuclear = low present value – moderate start-up = negative NPV
NPVcoal = low present value – low start-up cost = neutral NPV

In the discussion of environmental clean up, discounting also plays a critical role. For the remediation of Superfund Sites, the Environmental Protection Agency (EPA) (2011) has asserted a discount rate of 7% to ensure consistency with the OMB’s standard investment interest-based discount rate. In assessing the total liability incurred to the U.S. taxpayers and individual parties for 4,500 Superfund Sites, the Congressional Budget Office (CBO, 1994) uses the 7% discount rate to calculate a present day cost of $75 billion from 1993 onward. The use of discounting in this method, which reduces the total cost of the Superfund Site cleanup effort over its projected lifetime, reflects the assertion that deferred cleanup and mitigation expenditures can be invested to fund future cleanup and mitigation measures.

Arrow et al. (1996) broadly discusses the inadequacy of social discount rates as used to evaluate Global Warming abatement measures, explaining that “the use of too high a discount rate will result in too little value placed on avoiding climate change and too little investment in climate change programmes” (p. 130). Daly & Farley (2004) give several specific examples, disclosing that a 6% social discount rate in one study resulted in the determination that $30 trillion in avoided future damages (in 200 years) from greenhouse gas abatement has a purported present day worth of only $300 million. The enormous disparity between the value of avoid ecological and social damages in the future and the calculated worth of those damages in present day terms is a significant factor in the decision *not* to undertake implement greenhouse gas abatement measures.

The social cost of carbon (SCC) is an economic value for the negative externality of greenhouse gas (GHG) emissions, which relies on social discounting to be ‘accurately’ determined due to the time-dependency of climate change effects. Sterner (2013) discusses the reality that the high social discount rates and protracted timeframes for global warming impacts lend to the relatively low SCC value of approximately $40 per metric ton of CO2. This low NPV of GHGs makes it difficult for greenhouse abatement actions to out-compete alternative investments, and emphasizes the need for a declining discount rate (addressing the uncertainty factor of discount rates, discussed later in this section) in order to properly revalue the NPV of carbon (Sterner, 2013).

The International Monetary Fund's (IMF) 2008 World Economic Outlook Reports that a comprehensive and progressive international CO2 taxation program would stabilize greenhouse gases at 550 parts per million while requiring only a 0.1% reduction in average international annual income (IMF, 2008). The intent of such a program would be to prevent the estimated 14% loss of social welfare (due to ecological harms and destabilization) over the next two centuries as a result of global warming (IMF, 2008). In the most liberal of analyses and despite such a immense potential ecological and social savings, the social discount rate would have to be as low as approximately 2.5% to motivate this international GHG abatement program. Even the OMB's lower social discounting standard of 3% (the OMB uses both a market-based individual discount rate of 7% and a lower social discount rate of 3%) would not promote such a conservative international climate change action (Arrow et al., 2013).

### *Environmental Critiques of Discounting*

Discounting is a heavily debated topic. The debate on discounting takes many forms and is of such breadth and complexity, as Price (2006) and Geraats (2006) highlight. Additionally, the many separate viewpoints on the topic derive from varied academic circles, including those of economists, political scientists, philosophers, psychologists, and ecologists and natural resource managers. The specifics of the debates on discounting are varied and include topics such as determining the types of economic and resource decisions to which discounting should be applied; determining what fundamental methodology (e.g. positive or normative) should be used to derive social discount rates; and determining what specific factors and data should be accounted for when calculating social discount rates. One of the most common academic debates amongst circles of resource and economic professionals continues to be the impact of discounting on social wellbeing and ecological sustainability. Simply put, discounting is pivotal to the sustainable management of both resources and civil societies – both of which are time-dependent. Moreover, Beltratti et al. (1993) assert that the two central topics in the idea of sustainability – resource constraints and intergenerational equity – are still nascent; and, "…of these two factors [resource constraints and intergenerational equity]… the issue of intergenerational equity is the one that is more inadequately treated in the existing literature" (Beltratti et al., 1993, p. 5). Heal (2005) sums up these challenges in his assessment that granting intergenerational equity is "not in general possible" when working with "infinite horizons and a roughly utilitarian framework" (p. 1109).

Arrow et al. (1996) outline the significance of the debate on resource constraints and intergenerational equity in the article, "Intertemporal Equity, Discounting, and Economic Efficiency". Arrow et al. (1996) describe the contentious nature of the ecological debate on discounting from both sides of the methodology (normative versus positive) schism, elucidating the negative social and environmental impacts of both the prescriptive (normative) and descriptive (positive) approaches. The authors clarify that current descriptive approaches for social discount rates, using investment interest rates, tend to grossly undervalue the present day equivalent value of any future ecological (or social) benefit, negating or at least undermining present day movements for the benefit of future generations (Arrow et al., 1996). Conversely, the authors also critique the prescriptive approach, which often incorporates a factor that devalues future generations, as well as a decrease in marginal utility inversely proportional (by a marginal utility elasticity constant) to an assumed increase in consumption and social wellbeing of future generations (Arrow et al., 1996). They explain that such a method often results in discount rates that are excessively low, favoring specific ecological actions today vice the investment of money or resource alternatives, thereby supplanting the ability for present, future, and interim generations to exercise choice in their use of capital (Arrow et al., 1996).

Arrow et al. (1996) also contend that the prescriptive approach does not always reflect behavioral reality in the marketplace. For example, the variable that devalues future generations is often assigned a quantity of zero, reflecting the ethical argument that future generations harbor the same ‘worth’ as present generations. However, actual development expenditures for countries in the Organization for Economic Co-operation and Development (OECD) reflect that a higher value (effectively devaluing future generations) is empirically more relevant, given the relatively sparse economic and resource focus that is placed on such purposes (Arrow et al., 1996). This argument, however, may be negated by the very fact that prescriptive approaches are intended to reflect what *should be* – especially from an ethical, social, and environmental perspective – vice what empirically *is*.

In perfect concert with this dichotomy of what ethically ‘*should be*’ versus what objectively ‘*is*’, Daly & Farley (2004), contend that future generations are actually growing poorer when accounting for negative externalities, despite the fact that consumption data depicts the contrary (Arrow et al., 2013). If prescriptive methods accounted for the hidden reality of increasing marginal utility due to decreasing living standards from negative externalities (vice the current assumption of decreasing marginal utility), social discount rates would decrease, motivating present day actions for future ecological benefits (Arrow et al., 1996; Arrow et al., 2013). Thus, scholars contend that prescriptive approaches should account for social and ethical standards (e.g. consideration of negative externalities), vice the empirical realities of the unregulated marketplace.

Rabi (1996) recognizes that discounting undermines future social welfare through the use of investment interest rates in long-term cost-benefit analyses. He contends that the use of such rates, when used past the standard term of a market financial investment instrument, falsely assume an indefinite creation of wealth vice a redistribution of resources between generations (Rabi, 1996). Similarly, both Weitzman (1998) and Arrow et al. (2013) evaluate the negative consequences of fixed social discount rates on long-term projects. Using Global Warming as a key example, Weitzman (1998) and Arrow et al. (2013) both describe that, given the exponential design of discounting, the uncertainty of future discount rates yields a heavy mathematical weighting (or preference) towards low discount rates. Resultantly, even the lower of the two fixed social discount rates used by the OMB (the consumption rate, which accounts for the decreasing marginal utility of future generations due to increasing consumption to yield a 3% discount rate – lower than the private investment rate of 7%) is inadequate when evaluating social and ecological actions that have intergenerational effects (Arrow et al., 2013). In contest, Weitzman (1998) and Arrow et al. (2013) both propose a declining discount rate to mirror the time-dependent uncertainties of resource and intergenerational valuations.

Heal (2005) asserts clearly that fixed-rate discounting yields a clear and unwarranted disadvantage to the future when dealing with long term ecological issues such as global warming. Beltratti et al. (1993) also offers a synopsis of the ecological debate on social discounting, stating that “a positive discount rate forces a fundamental asymmetry between present and future generations… this asymmetry is troubling to many who are concerned with environmental matters such as climate change, species extinction and disposal of nuclear waste, as many of the consequences of these may be felt only in the very long run indeed" (p. 6). Congruent with this critique, Beltratti et al. (1993) recommend a normative approach that is "temporally symmetric", in abidance with the sustainability criterion to not undermine the ecological well-being of future generations, including those in the "very far distant future" (p. 7). Arguing along similar lines, Sumaila & Walters (2005) assert that contemporary discounting measures under-represent the ecological needs of the future beneficiaries, as future generations are not present to participate in the cost-benefit decision.

Schelling (1995) heavily criticizes the primary inputs of social discount rates for their ecological and social shortcomings, asserting that marginal utility standards are grossly inaccurate due to the false assumptions that they are uniform across nations, years, and consumption levels (constant slope or income elasticity of utility). In reality, he argues, marginal utility rates have differing income elasticities (slopes), and need to be disaggregated both temporally ("according to the levels of per capita consumption at which they accrue") and spatially (by nations and their development status) (Schelling, 1995, p. 398). Additionally, Schelling (1995) contends that the market interest rates do not accurately reflect peoples' desires to aid future generations, and poorly represent the returns possible via social and ecological investments in poor countries in lieu of long term initiatives such as global warming mitigation.

Addressing the psychological and behavioral aspects of intertemporal discounting, Geraats (2006) uses empirical consumption data (a descriptive approach) to determine that the assumption and use of fixed exponential discount rates leads to significantly larger intertemporal substitution and consumption rates given a permanent price change. However, if hyperbolic discounting methods are assumed by consumers (e.g. discounting rates decreasing with time due to factors such as uncertainty (Weitzman (1998); Arrow et al. (2013)), and the weighted time factor (Sumaila & Walters, (2005)), any persistent change in interest rates results in a decrease in the elasticity of intertemporal substitution (people are *less* willing to substitute contemporary investments or consumption for future resource benefits). An exponential (r = constant) discount rate risks overstating the benefits of private investment policies such as tax cuts by undervaluing the NPV of future social and resource benefits of projects, in comparison to more precise hyperbolic (decreasing) discount rate (Geraats, 2006). From a social and ecological perspective, the implications of these findings are that social and environmental projects don't compete nearly well for capital under exponential discount rates.

An analog to the hypothesis of intergenerational valuations examined in this study, Pozdena (2011) recognizes the reality that current discount rates do not accurately account for society's preference for current consumption versus preservation of resources for the future. The author's example elucidates this disconnect, stating that current social discounting practices are "inconsistent with widely observed bequest activity, and other voluntary sacrifices of current consumption to preserve assets and resources for future generations. Indeed, in 2010 alone, over $191 billion in estate bequests were filed with the Internal Revenue Service (IRS). Bequeathing such estates, instead of consuming them over one's lifetime, will tend to put downward pressure on observed interest rates, with the same effect on discount rates" (Pozdena, 2011, para. 12).

*Proposed Improvements to Social Discounting Rates*

Numerous recommendations from economists, ecologists, and political scientists accompany the many critiques of social discount rates. Arrow et al. (1996) recommend accounting for tax liabilities in a descriptive social discount rate. If accounting for such, social discount rates would be significantly lower than assumed when strictly using investment interest rates. As an example "…in the OECD countries, equities have yielded over 5% (after corporate and other taxes) for many decades, which is comparable to a pretax rate of at least 7%" (Arrow et al., 1996, p. 133). Arrow at al. (1996) also implicitly acknowledge the time-dependent variability of resource prices – a factor examined in this study's correction of social discount rates – though without specifically giving a correction factor other than through the accurate estimation of future prices. The authors state, "Many people expect the relative price of environmental goods to increase over time, which would have consequences equivalent to adopting a lower discount rate for such goods at unchanged prices" (Arrow et al., 1996, p. 130).

Weitzman (1998) and Arrow et al. (2013), using a predominantly positive approach, account for the statistical "uncertainty in the rate of growth in consumption and return to investment" to beget a declining discount function that calculates the average of the exponential function with variable discount rates (p. 350). The result of the declining discount rate (DDR) (with the exponential outputs averaged around the uncertainty thresholds) is a much greater NPV (net present value) than through the use of fixed discount rates that averaged around the same uncertainty thresholds (Weitzman, 1998; Arrow et al., 2013). This is due to the exponential discount function, which magnifies the decrease in NPV as r and t increase, yielding an average output value that is heavily weighted towards the lower r-value. Redressing the false premise that financial wealth can be created indefinitely, Rabi (1996) suggests the use of investment interest rates for only short-term projects and the use of GDP-per-capita growth as the social discount rate (1-2% internationally) for long-term projects, to better represent intergenerational redistribution of wealth and resultant marginal utilities.

Using a normative, resource-based methodology, Betratti et al. (1993) propose a social discounting method that introduces a concept coined as the “Green Golden Rule,” which “gives the highest indefinitely maintainable level of instantaneous utility” for a natural resource, and then uses a combination of resource logistics (or growth rate) curves, as well as consumption to calculate an optimal utility function. This optimal utility function is recommended as a replacement to determine consumption levels in lieu of the use of utilitarian discounting methods, resulting in a more symmetrical consumption rate between distant generations (Betratti et al., 1993).

Schelling (1995) proposes abandoning discounting (intertemporal optimization) entirely and replacing it with an analytical policy approach that accounts for the specific marginal utility of recipient nations as a result of present day actions. This manner would allow temporally and spatially specific marginal utilities to be considered, yielding a more accurate cost-benefit comparison of “what we get for our money” (Schelling, 1995, p. 400). In another attempt to better represent beneficiaries in different generations, Sumaila and Walters (2005) contend that future ‘stakeholders’ should be accounted for using a weighted discounting function with an adjusted discount rate and reduced time, t, for each subsequent group of stakeholders. In this manner, the intergenerational stakeholders’ delayed ‘entry’ in the stakeholder population will yield higher NPVs due to the lower combined t value for the entire stakeholder population and the fact that discounting values decrease exponentially as a function of time, t.

In a similar argument, Frederick (2006) recognizes a clear distinction between “discounting one’s *own* future utility and discounting the utility of *others* who will be alive in the future”, and contends that discounting for intergenerational purposes should be conducted using a normative argument centered around society’s preference for maintaining intergenerational equity. Additionally, Carmody (2012) recommends a discounting approach that uses both empirical evidence and ethical judgments to prescribe a “distribution of resources between generations” appropriate for the project being evaluated (para. 50).

As obviated by the aforementioned critiques of and recommendations for social discount rates there is a gap in the academic literature. No published works address using a descriptive approach, operating within the neoclassical economics framework, in order to modify the individual/market-based discount rate (investment interest rate) for appropriate economic realities to beget an improved social discount rate. This study examines this in an attempt to: 1) evaluate the viability of neoclassical economic principles for improving ecological resource conservation and sustainability, and if proven viable, 2) provide a simple and universal approach using existing global economic conventions for motivating increased resource conservation and improving sustainability.

## IV. METHODOLOGY

### *Normative versus Positive Approach*

As Arrow et al. (1996) describes, two fundamental methods can be used to determine social discount rates. The prescriptive, or normative (ends-based), approach begins with the end in mind (such a social end via a social welfare function), and then uses that to calculate the discount rate (Arrow et al., 1996). The underlying premise in the use of the prescriptive approach is that the discount rate is “derived from ethical considerations, reflecting society’s views concerning trade-offs of consumption across generations” (Arrow et al., 1996, p. 131). A descriptive, or positive, approach relies on the use of real world investments and “sets the discount rate accordingly” in order to achieve a maximization of benefits and to “maximize the economic resources available to future generations” (Arrow et al., 1996, p. 132). In this manner, empirical economic data, such as producer or consumer interest rates, are used in an attempt to maximize net benefits intertemporally through discounting.

This study uses a positive, or descriptive (empirical data-based) approach, upholding the prevailing neo-classical economic framework in environmental economics. In doing such, this study answers the question of whether neoclassical economics offers a suitable method of modifying social discount rates to improve resource sustainability, using a descriptive approach to account for various economic realities that are missing from current social discount rates.

With the burgeoning influence of environmental economics and time-dependent resource dynamics and constraints, neoclassical economics requires the consideration of temporal scales to maximize market benefits. Thus, if benefits are to be maximized for time, t, as well as quantity, discounting must be applied for all decisions affecting future ecological resources.

Additionally, because neoclassical economics functions by enabling individual market decisions to determine the equilibrium purchase/production quantities (‘spatial equilibrium’, where marginal supply equals marginal demand), it should utilize empirical data derived from these market decisions to determine the temporal equilibrium rate (r) for social discounting. As such, a positive/descriptive approach at adjusting social discount rates may promote improved sustainability in support of the ecological needs of future generations – even if abiding by neoclassical economic principles of achieving max benefit/efficiency by accounting for the effects of individual, free market decisions.

### *Discounting Flaws and Proposed Correction Factors*

This study examines the hypothesis that social discounting methods contribute to the degradation of natural resources and global sustainability by failing to account for: (1) Inflation due to monetary and fiscal policies; (2) resource and service cost increases due to other market dynamics; (3) resource cost increases due specifically to resource scarcities; (4) monetary versus resource substitutability; and (5) intergenerational valuations. This study examines data for the aforementioned economic factors and uses the data to determine a correction factor for social discounting. This study also proposes a modified discounting equation and applies the aforementioned correction factors into this equation to achieve an improved (i.e. reduced and time-dependent) social discounting rate.

The sub-hypotheses examined in this study are:

1. Monetary inflation rates for the U.S. Dollar (USD) have remained consistently positive, yielding overvalued discount rates over the examined timeframe (46 years from 1967

through 2012). Refer to Appendix B for further explanation of the use of inflation rates in current discounting methods.

2. Many goods and services experience price adjustments different from standard inflation rates due to other distinct market dynamics (dissociated from the monetary influences that drive inflation). Such price adjustments, if greater than average inflation rates, yield further-overvalued discounting rates, and may have a time-dependency that is different from goods subject to standard inflation rates (in #1 above).

3. Natural resource scarcities have yielded cost increases that may further overvalue discount rates as applied to over-harvested/constrained resources.

4. Prevailing discounting methods assume that money is perfectly substitutable for future resources, giving equal preference towards present-day financial investments in lieu of present-day actions that bear future resource and ecological yields. This ‘equal substitutability of money for resources’ may not be accurate based on objective or empirical market standard and *may* overvalue discounting rates if market realities reflect a preference for investment in resources over financial instruments.

5. Prevailing discounting methods do not account for our valuation of future generations. If such valuations of future generations (as a ratio of our valuation of current generations) are other than unity, current discounting methods risk unnecessarily moderating social discount rates. Refer to Appendix B for an explanation of marginal utility and its common application in determining social discount rates.

### *Discount Rate Correction Factors – Explanation and Quantitative Representations*

The proposed modified discounting equation is presented below:

$$PV=\sum FV/(1+ r')^t$$

The modified discount rate, r', attempts to correct for intergenerational and ecological inequity of environmental benefits by accounting for current monetary and resource dynamics, resource vs. monetary substitutability, and intergenerational valuations:

$$r' = \{1 / [g_v(t) * f_v(t)]\} \text{ x } [r – i']$$

$$\text{where } i' = {}_{p=1}\Sigma^n [i_p(t) * (a_p/K)] + i_s * (a_s/K) + i_r(t)$$

KEY:

$r$ = standard investment interest rate

$i_p(t)$ = cost consumption-based weighted average cost increase/inflation of market commodity p, as a function of time (t), to account for resource and service market dynamics (in addition to monetary inflation)

$i_s$ = standard rate of core inflation (total inflation less food, shelter, and energy)

$i_r(t)$ = real (inflation-adjusted) price change (rate) due to resource scarcities

$a_p$ = unit-less weighted value or importance, relative to K=100, of total market funds expended by consumers on market commodity n

$K = {}_{p=1}\Sigma^n [a_p] + a_s = 100$, by convention (BLS, 2012a)

$\therefore\ a_s = K - {}_{p=1}\Sigma^n [a_p]$

$f_v(t)$ → the relative valuation of holding resources as wealth versus financial investment instruments or paper money as wealth (as a ratio of U.S. annual average per-capita expenditure on resource investment instruments versus financial investment instruments)

$g_v(t)$ → function modeling society's valuation of future generations (with respect to t, t = 0 being present time) as a fraction of the valuation of present generations, (e.g. $g_v(0) = 1$)

The following descriptions and explanations are offered for this study's proposed social discounting correction factors, corresponding (by number) to sub-hypotheses 1 through 5. Each of these correction factors will be analyzed and applied to the modified discounting equation to achieve a new social discount rate:

1. Inflation. On the international market the inflation rate of a currency (e.g. of the USD) is analogous to the exchange rate of that currency, e. The quantity theory equation states that a nation's monetary supply ($M^s$) is equal to the product of the nation's domestic product (Y), the relative price level of goods (P), and k (the demand for money, i.e. to facilitate resource purchases):

$$M^s = k * P * Y.$$

Rearranging variables, the price level of goods (P) is determined to be:

$$P = M^s / (k * Y).$$

Comparing the price level (P) of one nation to another (or to the international aggregate) yields the following ratio:

$$e = P / P_f = (M^s / M^s{}_f) * (k_f / k) * (Y_f / Y)$$

This relationship highlights the fact that a nation's inflation rate, or its currency exchange rate, e, is a function of demand for money (k), domestic production (Y), and monetary supply. Given that k is commonly viewed as a constant in the long run by economists, and that domestic versus foreign domestic product ratios are often nominal in the long run as well, monetary supply tends to play the largest influence on inflation (Pugel, 2012). According to Pugel (2012), "economists believe that the money supply (or its growth rate) determines the price level (or the inflation rate), in the long run" (p. 459). For the purpose of this study, the importance of this mathematical relationship is recognizing that exchange rate trends, based on monetary demand, monetary supply, and domestic product, are assumed to affect the price (P) of all products and resources equally. Empirically, inflation rates are determined based on the Consumer Price Index (CPI), which accounts for the average, unit-less price of a standard 'basket' of goods relative to the unit-less benchmark of (100) for 1982 to 1984 (BLS, 2013).

2. A determination of goods and services that are exceptions to the CPI 'basket' – those not accounted for in determining the CPI – and experience price adjustments different from the CPI due to specific resource/social/political dynamics vice due to the nation's monetary policies, GDP, and monetary demand. Though it is critical to account for inflation in determining a social discount rate, the 'basket' of goods used to quantify overall inflation rates based on monetary policy purposefully excludes food and energy costs, as they experience significantly different inflation rates due to factors *other* than those determining the exchange rate, e (BLS, 2008).

The U.S. Bureau of Labor Statistics (BLS) (2008) publishes the inflation rates for a comprehensive set of nearly *all* goods for the majority (87%) of U.S. consumers through their "All Items CPI for All Urban Consumers (CPI-U)" (para. 1). The BLS also publishes price indices excluding items that "are volatile and are subject to price shocks that cannot be damped through monetary policy" (BLS, 2008, para. 1). The most commonly used of these amongst economists and politicians is referred to as "CPI-U for All Items Less Food and Energy" (BLS, 2008, para. 1). Another (and the most comprehensive) such index is the "CPI-U for All Items Less Food, Shelter, and Energy" (BLS, 2008, para. 1). As their names imply, these inflation indices exclude food, shelter, and energy costs due to the fact that price changes for these resources are less representative of monetary policy than they are of other social, environmental, and geopolitical dynamics. This study uses the "CPI-U for All Items Less Food, Shelter, and Energy" in one data analysis (inflation), and examines the time-dependency of prices for each of food, shelter, and energy in separate analyses. In recognition of the separate causal factors that beget each rate of inflation, this study divides these analyses to examine the potentially disparate correlations of each rate of inflation with respect to the independent variable of time (yielding distinct time-dependent functions). This study abides by the assumption that future resource values under social discount analysis are subject to all inflation rates (both of the CPI-U Less Food, Shelter, and Energy; as well as the more volatile Food, Shelter, and Energy-specific inflation rates) at the same relative (consumption-based) weights used to determine the overall (inclusive) inflation rate.

3. The lack of consideration for forecasted resource scarcities, and resultant market cost increases are a factor that can negatively impact (artificially increase) discount rates, if not accounted for. Money and resource 'worth' are based on the ability to purchase, and substitutability for, other resources. However, constrained renewable resources, or those that have been over-harvested and reduced to a quantity that is below the resource's sustainable yield, risk devaluing the substitutability of money for resources (Daly & Farley, 2004). If the earth's

natural resources experience availability reductions and associated cost increases, the worth of money as a substitute for such resources should decrease with an inverse proportionality to the average of such increases. The same relationship holds true for a decrease in GDP (e.g. as a result of resource constraints), as determined by the quantity theory equation presented earlier. This will effectively lower discount rates (conservatively assuming the discounted resources are subject to the same scarcity-based cost increases as the aforementioned 'average'). It is important to note that the following two factors make this resource-specific cost adjustment applicable to the social discount rate, as a distinct and separate item from inflation rates:

a. Resource scarcities play a negligible role in determining inflation rates – a verity supported by a number of prominent U.S. economists, including Blackman & Baumol (2008) and Krugman (2011b). This is predominantly due to the fact that, per the Federal Reserve Bank of San Francisco, "commodities account for only about 5 percent of personal consumption" (as cited in Krugman, 2011b, para. 4). Thus, whatever inflation scarce resource commodities experience yields a nominal shift in overall inflation values.

b. Social discounting is applied to resources at risk of future scarcity. This assumption is held as self-evident for any intertemporal environmental economic issue, given the unsustainable consumption profile of 1.5 Earths that the global human population is currently on (Borucke et al., 2013).

The following conclusions can be drawn from the two aforementioned factors: Future resources will uphold an increase in resource purchase power and monetary valuations due to inflation (a combination of the consumption-weighted standard inflation rates plus the consumption-weighted energy and food inflation rates); and, future *constrained* resources will yield an *additional and intrinsic* change in resource purchase power and resultant monetary valuations based on scarcity-derived price dynamics (adjusted for inflation).

Assuming the aforementioned factors to be true, a sampling of resource scarcities and real (inflation adjusted) price levels are analyzed and applied to discount rates in this study's modification of the social discount rate.

Moreover, though this study examines discounting through a positivist (vice normative) lense, application of the precautionary principle is worthy of discussion when considering the correction factor of resource scarcities. *If* resource scarcities are accurately considered when discounting, then the scarcities (as well as associated resource price increases) may not materialize due to reduced social discount rates. Conversely, if scarcities are *not* considered in discounting, then the scarcity-driven cost increases *will* likely materialize, thereby underestimating present values for future resources. Simply put, accounting for potential scarcities in discounting may actually aid in their prevention or mitigation. Per the precautionary principle, such resource 'forecasting' should emphasize, rather than preclude, the need to use resource scarcities as a correctional factor to social discount rates.

4. Valuation of resource versus monetary investments (e.g. paper money, stocks, bonds, or other monetary investment instruments) and an analysis of the "substitutability" of money for resources. Contemporary discounting methods assume perfect substitutability of monetary financial instruments for future resources. By stating that any future resource holds an equivalent present monetary value based upon a financial investment interest rate, r, contemporary discounting methods implicitly assert that monetary financial investments hold *equal* values to resource-based investments. Though neoclassical principles assert that the

unregulated market establishes accurate monetary values for resources based on free market supply and demand interactions, such monetary values may not necessarily reflect the ostensibly ‘rational decisions’ of individuals in the market place when dealing with time-dependent investment decisions and determining how to manage their monetary holdings. Thus, the monetary cost of resources, as established by the neoclassical market system, *may not* accurately represent the *comparative* value of money versus the resources (money as a substitute). Simply put, asking the marketplace consumer *how much* money they would spend on a given resource will yield a different result than asking the marketplace consumer what *fraction of their total wealth* they would choose to spend on monetary/financial investment instruments vice on resources.

Instead of assuming a direct substitutability of money for resources based on the present day neoclassical marketplace (as determined by contemporary market actions), individual investment priorities and valuations are used in this study to determine a ‘substitutability ratio’ for discounting. This ‘substitutability ratio’ is applied to discount rate, r, due to the fact that it represents an investment preference of individuals in the marketplace, vice a present-day appropriation of monetary value to any resource.

Though a divergence from the method of determining resource costs through neoclassical market functions, this study contends that this analysis upholds neoclassical economic principles by leveraging objective and quantifiable data from individual investment decisions (in conjunction with conventionally-determined market costs) to modify discounting rates so that they more accurately reflect resource versus monetary substitutability and individual valuations of the same.

5. Valuation of future generations. Neoclassical economics assumes that people make rational decisions in the market place, and that such rational decisions (in combination with production costs) serve as one of the primary factors for determining pricing and equilibrium purchase quantity in the market place. In addition to explicitly controlling for equilibrium purchase quantity and price, consumer marketplace decisions also implicitly reflect intergenerational valuations. National productivity, or GDP, is a primary factor in the assignment of resource price levels in neoclassical economics (Pugel, 2012). For simplicity and in the absence of specific purchase data or algorithms assigning intertemporal valuations based upon individual market purchases, GDP (per capita) will be used by this study as a macro indicator of individual productivity over time, and thus intergenerational valuations.

### *Data Collection Methods*

Data for this study were gathered from valid data reference sites including the Bureau of Labor Statistics (BLS), the World Bank Group, Trading Economics, the U.S. Census Bureau, and the Bureau of Economic Analysis, using the United States' population, sample timeframe objectives from 10 to 61 years (varying with each individual correction factor), and one year/annual as the standard sample increment (data permitting).

The below historical data sets, corresponding (by number) to sub-hypotheses 1 through 5, were extracted and analyzed:

1. Inflation values, $i_s$, (USD):

These data were gathered using CPI-U data, less food, shelter, and energy, from the Bureau of Labor Statistics (2013) from 1967 through 2012 for the United States, as a function of time, with one data point collected for each year (totaling a sample size of 46 due to data source limitations). Inflation values were determined by calculating the annual percentage increase in CPI for each subsequent year. The data were averaged over the entire time period to determine a correction factor to the market-based interest (discount) rate.

2. Resource costs for resources and services (food, shelter, and energy) not accounted for in the volatility-adjusted inflation indices used in study #1, above, $i_p$:

These data were gathered from the Bureau of Labor Statistics (2013) for the United States, as a function of time, with one data point collected for each year (totaling a sample size of 50). CPI/inflation data for food, shelter, and energy were gathered as separate data sets for 1963 through 2012. Inflation values (or ‘cost increase rates’) were determined by calculating the annual percentage increase in CPI for each subsequent year. The data were used to determine a time-dependent correction factor and weighted against the average percentage household expenditure of income on these resources.

Weighted consumption values for this study’s modified social discount rate, ($a_p$/K), were determined using the BLS (2012a) “Relative importance of components in the Consumer Price Indexes” from December 2012.

3. Resource costs for a selection of constrained renewable and non-renewable natural resources, $i_r$:

Cost data were gathered using CPI data from BLS (2013) and Mongabay Conservation and Science News (2013) on a selection of two supply-constrained renewable and two supply-constrained non-renewable resources (declining extraction due to supply and/or technological limits). These data were gathered for one decade, from 2002 to 2012, to best approximate more recent trends of resource declines and possible associated cost increases. One data point was collected for each year, for a total sample size of 10. The costs were converted to 2013 equivalent dollars using the BLS (2013) inflation calculator and divided by the 2002 value to achieve a normalized cost index (CPI'). These normalized values were used to determine year-to-year cost increases, or scarcity-based inflation rates ($i_r$), for the constrained resources. These output data were checked for time-dependency and then weight-averaged with each other using the CPI 'relative importance' ratios to create an inflationary correction factor to the social discount rate (BLS, 2012a).

4. The relative valuation, or importance, to society of holding resource investments versus financial investments, $f_v(t)$:

This was determined by analyzing the expenditures of the U.S. population on resource investments versus financial investment instruments for 2012. These data were gathered for consumers ages 25 through "75 and older" for the United States, as a function of time, with one data point collected for the *middle* of each year group represented by the BLS (2012b) data (totaling a sample size of seven over a time period of 61 years from adulthood, 18, until the average U.S. life expectancy). The data were analyzed for a time correlation and transformed into a ratio of resource versus financial expenditures (R / F). This ratio was used to determine a time-dependent correction factor ($f_v(t)$) to the market-based interest (discount) rate that accounts for the substitutability of money for resources.

5. Intergenerational valuation as a function of time (from a datum of $t = 0$ = present time), $g_v(t)$:

This will be represented as a ratio of the valuation of future generations to the valuation of present generations, as a function of time, t. One method of deriving this function is through peoples' willingness to pay (WTP) for future generations. Another method of deriving this, in alignment with neoclassical principles, is by determining the average economic per capita productivity as a function of time, t. For this study, this factor was determined by analyzing real average per capita productivity adjusted for inflation ('real' GDP, using chained 2009 dollars) of the U.S. over 60 years from 1950 to 2010 and then averaging the results for each 20-year generational periods (1950-1970, 1960-1980, 1970-1990, 1980-2000, 1990-2010, 2000-2020) to determine an intergenerational valuation function of time, t. NOTE: The per-capita GDP data for 2020 was calculated using the U.S. Census Bureau's (2012) forecasted population for 2020 and the GDP rate of increase (or slope) from the BEA's (2013) inflation-adjusted GDP outputs for 2010 to 2012. Data was extracted using decadal time increments for a total sample size of eight.

Outputs from the above data sets were then incorporated into this study's proposed modified discounting equation.

### *Statistical Analyses*

The aforementioned data outputs were analyzed for statistical significance using Microsoft Excel 2004 (version 11.6.6) software. The following statistical methods were used to analyze their respective data sets, 1 through 5.

1. Pearson Correlation – using time, t, as the independent variable; and inflation as the dependent variable.

2. Pearson Correlation – using time, t, as an independent variable; and resource costs and cost increase rates as the dependent variable.

3. Pearson Correlation – using time, t, as an independent variable; and resource costs and cost-increase rates as the dependent variables.

4. Pearson Correlation – using time, t, as the independent variable; and resource versus financial instrument ratios as the dependent variable.

5. Pearson Correlation – using time, t, as the independent variable; and the previously described intergenerational per capita real GDPs ratios as the dependent variables.

The alpha level for statistical tests was set at 0.05 for first order time-dependency to determine whether cost and valuation quantities indicate a correlation with time. The alpha level was set at 0.001 for second order time-dependency to determine whether first-order differential/time-dependent functions, such as inflation rates, indicate a correlation with time.

A standard p-value of $p < 0.05$ was used for CPI (cost) data to determine whether the hypotheses of time-dependent costs and valuation ratios were true (whether the null hypotheses were rejected). If the null hypotheses were rejected for CPI data, then an interest rate correction factor would be appropriate. However, that interest rate correction factor would be a constant if the first-order differential (interest rate) correlation's p-value was not of very high confidence ($p>0.001$).

The reason for choosing the p-value, $p < 0.001$, for the first-order differential (e.g. interest rate) statistical analyses, is to ensure a very high level of confidence in the time-dependency of interest rates before appropriating a time-dependent, other-than-constant, function that would be used to forecast (future) intertemporal discount rates. Forecasting rates through the use of of historical interest rate trends requires extremely high confidence in the empirically-derived historical trends. This helps prevent co-divergent speculative pathways that, when combined, would easily undermine future intertemporal discount rates. Rephrased, it's difficult to deny the reliability of proven, empirical historical data and its resultant average. It's very challenging, however, to assert the verity of forecasting functions and their future data *speculations*, even if derived from proven historical data. Due to the inherent risk involved with stochastic speculation of future rate-based correction factors based on empirical data (vice deterministic functions), it is more conservative to rely on a historical average, in the absence of an extremely reliable time-dependence of inflation rates.

Though a Type II error (failure to reject the false null hypothesis) is possible with a p value of $p < 0.001$, this is not a concern in this study’s cost-increase rate analyses. First, time-dependency/correlation of cost increases (or inflation) is simply not addressed in this paper’s hypotheses. Secondly, if this study conservatively accepts a *false* null hypotheses of lack of time-dependency for cost-increase rates, accepting such a ‘false null’ will beget the conservative, de facto, approach of determining *constant* rate corrections to social discounting based on empirically-derived historical inflation averages. Conversely, rejecting a *true* null hypothesis threatens the possibility of forecasting intertemporal discount rates based on a projected time-dependent rate equation. This is a much riskier proposition than correcting discount rates using historical averages as it is speculative by nature, and thus *assumes* accuracy of future rate corrections based on a *projected and estimated* function that is stochastically derived from historical (first-order differential) data.

### *Limitations of the Study*

1. Inflation values, $i_s$, (USD):

The inflation data were gathered from the CPI-U index, which reflects approximately 87% of urban consumers in the United States (BLS, 2008). Although these data provide the best single-source approximation of monetary-based inflation trends, they are not all-inclusive and are therefore subject to errors due to their lack of representation of the 13% of rural constituents in the U.S. Another limitation in the inflation data is the inability to dissociate additional price-volatile resources (such as education, transportation, and medical care) from the CPI-U index. The BLS (2013) currently does not publish an inflation index that decouples the aforementioned factors from the CPI. As a result the CPI-U core and “all items” indices will experience price influences from these more volatile factors, likely derived from other-than-monetary policy.

2. Resource costs for resources and services (food, shelter, and energy) not accounted for in the volatility-adjusted inflation indices calculated in data set one, $i_p$:

This study did not look at the additional factors that are commonly considered exceptions to monetary-derived inflation, such as medical/health services, education, and transportation. Such factors are all subject to additional volatilities that demand they be dissociated from the core inflation index to test for statistical significance and time dependence. This study limited its analysis to the separate examination of food, shelter, and energy for two reasons: 1) In conformance with the ‘core’ CPI (CPI-U less food and energy), which is “closely watched by many economists and policy makers under the belief that food and energy prices are volatile and are subject to price shocks that cannot be damped through monetary policy” (BLS, 2008, para.

1), and 2) Due to the BLS's lack of a CPI-U index that decouples transportation, medical, and education (in addition to food, shelter, and energy) from the CPI-U all items index.

Additionally, the CPI data for 'shelter' has gone through many changes over the past three decades, which may implement an artificial 'skew' to the continuity of this study's shelter-based inflation data. The methodology for extracting CPI-U shelter data changed in 1983 from being driven by homeownership costs, to being based on owner-occupied homeownership and rental costs, in order to exclude any investment aspect to homeownership costs (Ptacek & Rippy, 2013). The shelter CPI went through several more iterative changes in 1987 and 1998 to better account for rental and owner-occupied homeowner costs (Ptacek & Rippy, 2013).

3. Resource costs for a selection of constrained renewable and non-renewable natural resources, $i_r$:

The selections for constrained renewable and non-renewable resources were chosen randomly for this study. The purpose of this data examination was not to accrue an all-inclusive data set incorporating a comprehensive sample of scarce resources, but rather to provide a framework, or method, for accounting for resource scarcities in a modified discount rate using neoclassical principles. Existing studies were referenced to verify that the examined resources were, in fact, ecologically strained and past 'peak production'. However, for simplicity, the severity of resource scarcity was not comprehensively analyzed in this study, nor was the correlation between extraction rates and time. The correction factor for constrained resources has limited reliability due to the extremely small sample of data examined as well as the volatility and standard deviation of the data. As an example, copper and oil prices exhibit large fluctuations that are largely the result of geopolitical dynamics and demand-side pricing volatility, vice supply-side constraints (Kilian, 2013; Srinivas, 2011). Therefore, oil and copper price trends derived from supply-side resource constraints are likely overshadowed by these other confounding factors. Therefore, as an 'exploratory' measure and preempting further research on this specific correction factor, the modified social discount equation will be examined for three different applications of this correction: $i_{r1}(t)$ (excluding copper due to negligible consumption weight), $i_{r2}(t)$ (excluding copper and oil due to excessive standard deviation), and $i_{r3}(t)$ (excluding the entire correction factor due to inadequate sample size).

Although Blackman & Baumol (2008) state that price is one of the most reliable indicators of resource scarcities, any correlation between resource costs and time in this study's data is *not* an indication of causation between resource scarcity and cost. In this study, increasing costs were analyzed for correlation with time to substantiate the presumption of scarcity-derived inflation values for constrained resources. However, it is important to note that both resource extraction rates and resource costs are subject to a large variety of other confounding variables that were not examined in this study, including demand, resource substitutability, and technology and geopolitical dynamics. All of these confounding factors can skew price data and need to be analyzed in greater depth to determine their respective role in the resource's cost trends.

Additional data inaccuracies could be accounted for due to the following: the BLS incorporates water and sewer into one CPI index, thereby interjecting the added element of 'sewer treatment services' into the CPI index for water; the BLS accounts for oil prices by analyzing the U.S. city average of #2 fuel oil, vice for crude oil (BLS, 2013).

Lastly, there is some overlap between the cost-increase data for scarce resources and the inflation rates accounted for earlier in the CPI-U energy and CPI-U indices. The CPI-U energy index (and other CPI-U indices for scarce resources) implicitly reflects scarcity-derived cost effects through other-than standard inflationary cost changes. Thus, accounting for scarcity-based impacts through this entirely separate inflation-adjusted factor, weighted at unity, will yield some overlap and risks overvaluing this social discount correction. However, as stated earlier, the overall impact of resource scarcities on inflation is negligible, making this data overlap negligible and emphasizing the importance of accounting for resource scarcities as an independent correction factor to the social discount rate (Krugman, 2011b).

4. The relative valuation, or importance, to society of holding resource investments versus financial investments, $f_v(t)$:

The data that was gathered from the BLS (2012b) based on decadal age groups, granting a data point for every 10 years, vice for every year, and therefore limiting data robustness for the relative valuation, or importance, to society of holding resources as wealth, versus financial instruments as wealth, $f_v(t)$.

The determination of society's valuation for resources over wealth can only be partially represented and estimated using available neoclassical investment data. These data do accurately and empirically reflect society's preference for resource investments over financial investments, and therefore provide a reasonable estimation of the substitutability (or lack thereof) of money for resources. However, these data do not fully and perfectly reflect society's willingness to pay for natural resource conservation and other intergenerational social benefits. As a result, these data only provide a small, representative sampling of the comprehensive inputs required to determine society's complete willingness to pay now for future resources. Some of this 'gap' – specifically that of intergenerational valuation – is addressed in the next data analysis, which uses per capita GDP data to determine the neoclassical valuation of future generations as a function of time.

5. Intergenerational valuation as a function of time (from a datum of t = 0 = present time), $g_v(t)$:

Economic GDP data was limited to a start date of 1950 due to population data limitations (U.S. Census Bureau, 2012). The data set is also of reduced robustness due to decadal census collection intervals, resulting in the averaging of three data points during every generational period (20 years) to determine the intergenerational correlation. Additionally, the generational period of 2010 to 2020 was calculated via a combination of the available data and geometric interpolation, leading to a slight reduction in fidelity.

Per-capita real GDP is only one viable indicator of the economic valuation of citizens in a purely empirical neoclassical marketplace. Other indicators, such as per-capita workplace productivity (output per hour of input, vice per person) were not analyzed in this study. In order to make this social discount correction factor more accurate and complete, a more robust assessment of neoclassical principles and success indices needs to be conducted to determine their convertibility to intergenerational valuation standards. More importantly, though a viable indicator of intergenerational citizen worth *to the economic marketplace,* per-capita real GDP is arguably a very poor indicator of intergenerational worth to *the citizens themselves*. As exampled by this study, the valuation ratio, calculated by the relative real GDP of future-to-present generations, gets larger with time due to steadily increasing GDPs. Moreover, the valuation ratios are larger for early generations due to a slowing GDP growth rate (or a ‘decelerating’ GDP) ($d^2(GDP)/dt^2 < 0$) over the past half-century. Contrary to this valuation metric, economists commonly purport that consumers’ time-rate of preference (purchasing now vice later) and increasing wealth actually drive a discount rates up in preference for today’s generation. This study contends that the aforementioned metrics do not meet the constraints of a neoclassical approach. Conversely and however contentious and debatable the results may be, per-capita GDP provides a strictly empirical and descriptive approach at intergenerational valuation, $g_v(t)$.

## V. RESULTS

### *Individual Correction Factors – Quantitative Results*

Hypotheses 1 and 2. Inflation values (USD) and costs for resources and services (food, shelter, and energy) not accounted for in inflation indices were analyzed jointly. The results were as follows:

Inflation data and other resource costs were outlined in tabular form and represented by CPI and annual inflation values, as depicted in Table 1. These data were analyzed and graphed to determine trends and statistical significance. As depicted in Figures 2 and 3, the CPI and inflation of volatile resources such as food, shelter, and energy (in the specific case examined in this study) creates irregularities in the trend of the overall (“All Items”) CPI/inflation index. Thus, as discussed in the methods section, these items were dissociated from a base inflation index (CPI-U less food, shelter, and energy) in this study in order to conduct independent statistical analyses and determine if there were distinct time-dependencies of each sub-component.

The decoupled CPI (versus year) and inflation (versus time, t) curves are depicted in the graphs in Figures 4 and 5. These clearly show a consistently positive trend of inflation through an increasing “CPI-U less food, shelter, and energy” index, and through a consistently positive inflation rate (BLS, 2013). These graphs also depict the varying levels of volatility experienced by each of the additional factors not accounted for in the aforementioned inflation index: food, shelter, and energy.

| | All Items | | All Items Less Food, Shelter & Energy | | Food | | Shelter | | Energy | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | CPI | %I | CPI | %I | CPI | %I | CPI | %I | CPI | %I |
| 1963 | 30.60 | N/A | N/A | N/A | 31.10 | N/A | 26.10 | N/A | 22.60 | N/A |
| 1964 | 31.00 | 1.31 | N/A | N/A | 31.50 | 1.29 | 26.50 | 1.53 | 22.50 | -0.44 |
| 1965 | 31.50 | 1.61 | N/A | N/A | 32.20 | 2.22 | 27.00 | 1.89 | 22.90 | 1.78 |
| 1966 | 32.40 | 2.86 | N/A | N/A | 33.80 | 4.97 | 27.80 | 2.96 | 23.30 | 1.75 |
| 1967 | 33.40 | 3.09 | 38.70 | N/A | 34.10 | 0.89 | 28.80 | 3.60 | 23.80 | 2.15 |
| 1968 | 34.80 | 4.19 | 40.50 | 4.65 | 35.30 | 3.52 | 30.10 | 4.51 | 24.20 | 1.68 |
| 1969 | 36.70 | 5.46 | 42.40 | 4.69 | 37.10 | 5.10 | 32.60 | 8.31 | 24.80 | 2.48 |
| 1970 | 38.80 | 5.72 | 44.60 | 5.19 | 39.20 | 5.66 | 35.50 | 8.90 | 25.50 | 2.82 |
| 1971 | 40.50 | 4.38 | 46.80 | 4.93 | 40.40 | 3.06 | 37.00 | 4.23 | 26.50 | 3.92 |
| 1972 | 41.80 | 3.21 | 47.90 | 2.35 | 42.10 | 4.21 | 38.70 | 4.59 | 27.20 | 2.64 |
| 1973 | 44.40 | 6.22 | 49.30 | 2.92 | 48.20 | 14.49 | 40.50 | 4.65 | 29.40 | 8.09 |
| 1974 | 49.30 | 11.04 | 53.10 | 7.71 | 55.10 | 14.32 | 44.40 | 9.63 | 38.10 | 29.59 |
| 1975 | 53.80 | 9.13 | 57.80 | 8.85 | 59.80 | 8.53 | 48.80 | 9.91 | 42.10 | 10.50 |
| 1976 | 56.90 | 5.76 | 61.90 | 7.09 | 61.60 | 3.01 | 51.50 | 5.53 | 45.10 | 7.13 |
| 1977 | 60.60 | 6.50 | 65.60 | 5.98 | 65.50 | 6.33 | 54.90 | 6.60 | 49.40 | 9.53 |
| 1978 | 65.20 | 7.59 | 69.30 | 5.64 | 72.00 | 9.92 | 60.50 | 10.20 | 52.50 | 6.28 |
| 1979 | 72.60 | 11.35 | 74.10 | 6.93 | 79.90 | 10.97 | 68.90 | 13.88 | 65.70 | 25.14 |
| 1980 | 82.40 | 13.50 | 80.60 | 8.77 | 86.80 | 8.64 | 81.00 | 17.56 | 86.00 | 30.90 |
| 1981 | 90.90 | 10.32 | 88.30 | 9.55 | 93.60 | 7.83 | 90.50 | 11.73 | 97.70 | 13.60 |
| 1982 | 96.50 | 6.16 | 95.10 | 7.70 | 97.40 | 4.06 | 96.90 | 7.07 | 99.20 | 1.54 |
| 1983 | 99.60 | 3.21 | 100.00 | 5.15 | 99.40 | 2.05 | 99.10 | 2.27 | 99.90 | 0.71 |
| 1984 | 103.90 | 4.32 | 105.00 | 5.00 | 103.20 | 3.82 | 104.00 | 4.94 | 100.90 | 1.00 |
| 1985 | 107.60 | 3.56 | 109.00 | 3.81 | 105.60 | 2.33 | 109.80 | 5.58 | 101.60 | 0.69 |
| 1986 | 109.60 | 1.86 | 112.70 | 3.39 | 109.00 | 3.22 | 115.80 | 5.46 | 88.20 | -13.19 |
| 1987 | 113.60 | 3.65 | 117.00 | 3.82 | 113.50 | 4.13 | 121.30 | 4.75 | 88.60 | 0.45 |
| 1988 | 118.30 | 4.14 | 121.90 | 4.19 | 118.20 | 4.14 | 127.10 | 4.78 | 89.30 | 0.79 |
| 1989 | 124.00 | 4.82 | 127.30 | 4.43 | 125.10 | 5.84 | 132.80 | 4.48 | 94.30 | 5.60 |
| 1990 | 130.70 | 5.40 | 133.50 | 4.87 | 132.40 | 5.84 | 140.00 | 5.42 | 102.10 | 8.27 |
| 1991 | 136.20 | 4.21 | 140.40 | 5.17 | 136.30 | 2.95 | 146.30 | 4.50 | 102.50 | 0.39 |
| 1992 | 140.30 | 3.01 | 145.80 | 3.85 | 137.90 | 1.17 | 151.20 | 3.35 | 103.00 | 0.49 |
| 1993 | 144.50 | 2.99 | 150.80 | 3.43 | 140.90 | 2.18 | 155.70 | 2.98 | 104.20 | 1.17 |
| 1994 | 148.20 | 2.56 | 154.90 | 2.72 | 144.30 | 2.41 | 160.50 | 3.08 | 104.60 | 0.38 |
| 1995 | 152.40 | 2.83 | 159.30 | 2.84 | 148.40 | 2.84 | 165.70 | 3.24 | 105.20 | 0.57 |
| 1996 | 156.90 | 2.95 | 163.20 | 2.45 | 153.30 | 3.30 | 171.00 | 3.20 | 110.10 | 4.66 |
| 1997 | 160.50 | 2.29 | 166.40 | 1.96 | 157.30 | 2.61 | 176.30 | 3.10 | 111.50 | 1.27 |
| 1998 | 163.00 | 1.56 | 169.20 | 1.68 | 160.70 | 2.16 | 182.10 | 3.29 | 102.90 | -7.71 |
| 1999 | 166.60 | 2.21 | 171.90 | 1.60 | 164.10 | 2.12 | 187.30 | 2.86 | 106.60 | 3.60 |
| 2000 | 172.20 | 3.36 | 175.20 | 1.92 | 167.80 | 2.25 | 193.40 | 3.26 | 124.60 | 16.89 |
| 2001 | 177.10 | 2.85 | 178.70 | 2.00 | 173.10 | 3.16 | 200.60 | 3.72 | 129.30 | 3.77 |
| 2002 | 179.90 | 1.58 | 181.10 | 1.34 | 176.20 | 1.79 | 208.10 | 3.74 | 121.70 | -5.88 |
| 2003 | 184.00 | 2.28 | 182.60 | 0.83 | 180.00 | 2.16 | 213.10 | 2.40 | 136.50 | 12.16 |
| 2004 | 188.90 | 2.66 | 184.60 | 1.10 | 186.20 | 3.44 | 218.80 | 2.67 | 151.40 | 10.92 |
| 2005 | 195.30 | 3.39 | 188.10 | 1.90 | 190.70 | 2.42 | 224.40 | 2.56 | 177.10 | 16.97 |
| 2006 | 201.60 | 3.23 | 191.60 | 1.86 | 195.20 | 2.36 | 232.10 | 3.43 | 196.90 | 11.18 |
| 2007 | 207.34 | 2.85 | 194.21 | 1.36 | 202.92 | 3.95 | 240.61 | 3.67 | 207.72 | 5.50 |
| 2008 | 215.30 | 3.84 | 198.35 | 2.14 | 214.11 | 5.51 | 246.67 | 2.52 | 236.67 | 13.93 |
| 2009 | 214.54 | -0.36 | 202.63 | 2.15 | 217.96 | 1.80 | 249.35 | 1.09 | 193.13 | -18.40 |
| 2010 | 218.06 | 1.64 | 206.57 | 1.94 | 219.63 | 0.77 | 248.40 | -0.38 | 211.45 | 9.49 |
| 2011 | 224.94 | 3.16 | 210.50 | 1.91 | 227.84 | 3.74 | 251.65 | 1.31 | 243.91 | 15.35 |
| 2012 | 229.59 | 2.07 | 214.87 | 2.07 | 233.78 | 2.60 | 257.08 | 2.16 | 246.08 | 0.89 |

**Table 1. CPI & inflation data for various product groups, using CPI-U indices (Source: BLS, 2013)**

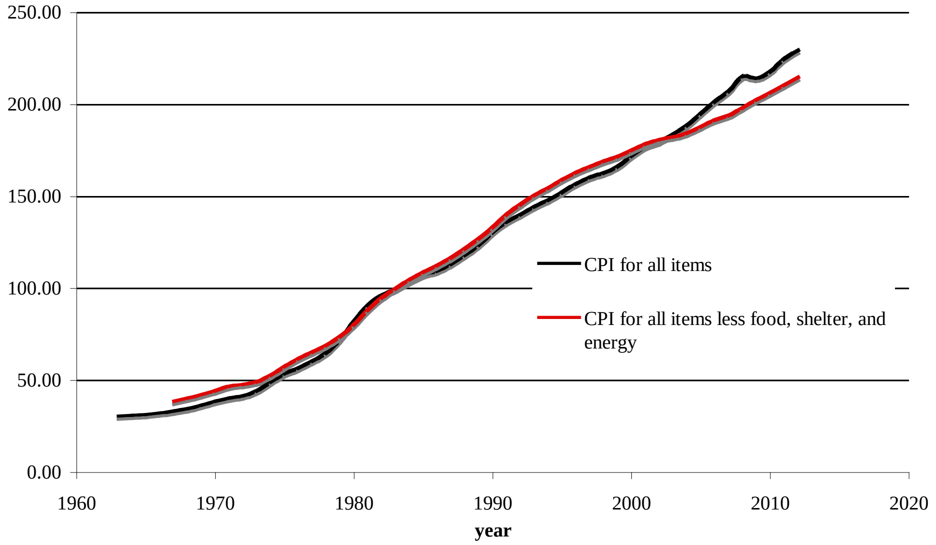

**Figure 2. Comparison of CPIs for:**
**- all items**
**- all items less food, shelter, and energy**

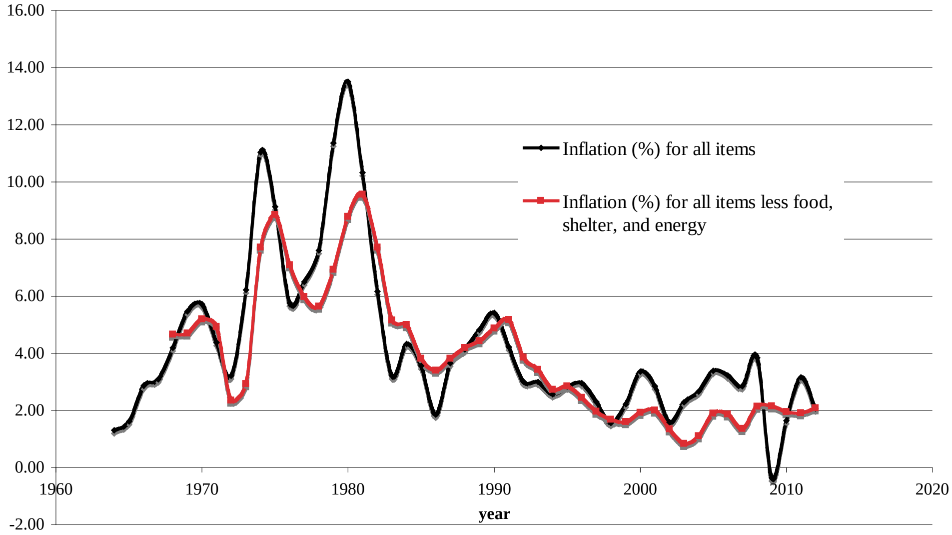

**Figure 3. Comparison of Inflation (%) for:**
**- all items**
**- all items less food, shelter, and energy**

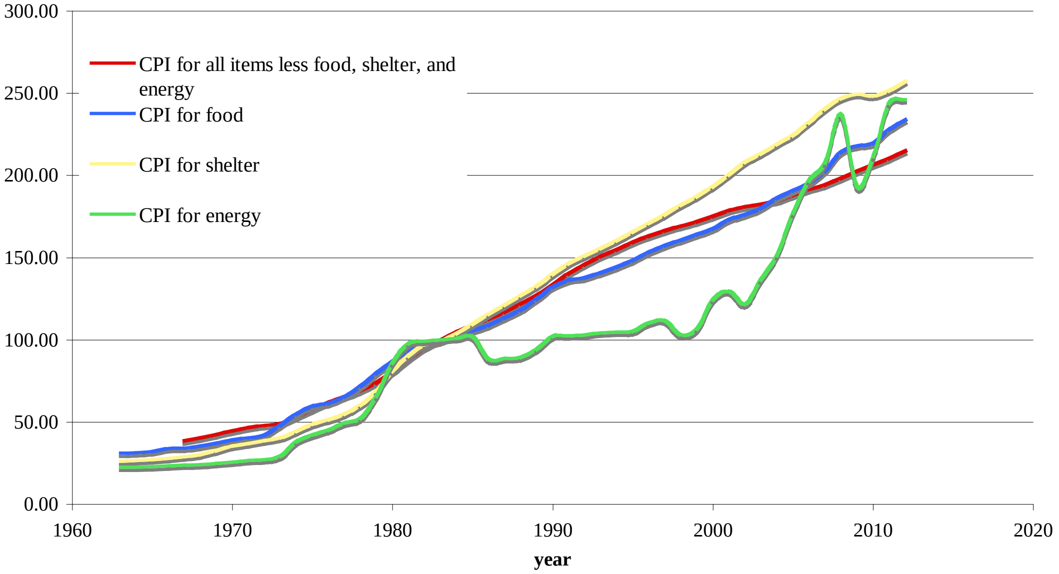

**Figure 4. Comparison of decoupled CPIs for:**
**- all items less food, shelter, and energy**
**- food**
**- shelter**
**- energy**

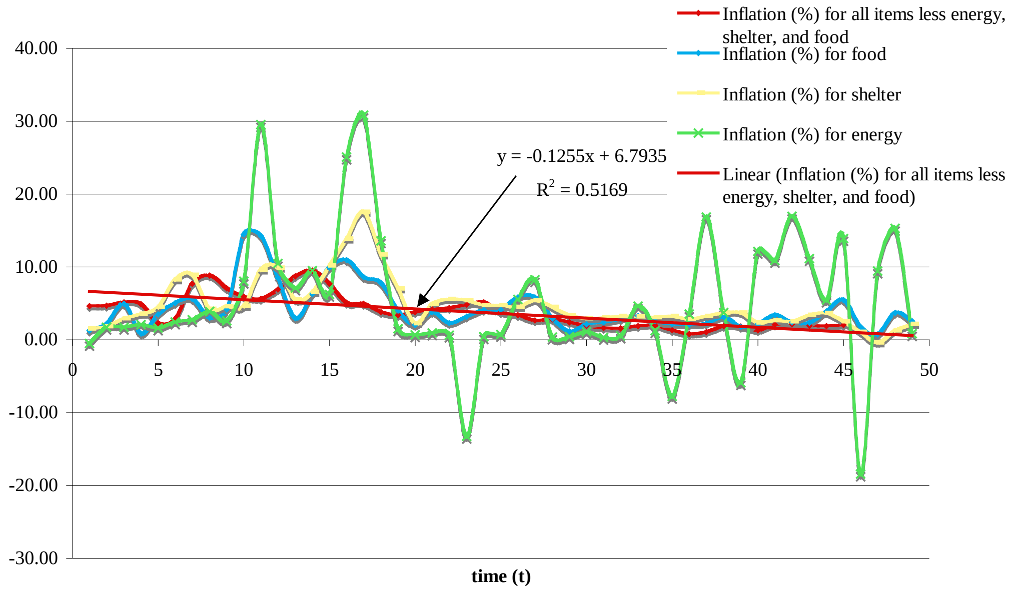

**Figure 5. Comparison of decoupled inflation rates (%) for:**
**- all items less food, shelter, and energy**
**- food**
**- shelter**
**- energy**

The Pearson product moment correlation test (Table 2) corroborated these graphs, depicting a strong positive correlation between CPI and time, t, for all examined CPI indexes. Using the CPI data for “all items less food, shelter, and energy”, the hypothesis that inflation rates are consistently positive was confirmed (null hypothesis rejected) with strong statistical significance. Additionally, the food, shelter, and energy inflation rates (%I) were analyzed using a very sensitive alpha value of 0.001 to determine whether their inflation rate ‘volatilities’ yielded a time-dependency that could reasonably be modeled. None of these three factors passed the statistical significance test for $p < 0.001$ for inflation. Though these factors’ inflation indices are normally *positive* with a high level of significance (as witnessed through their strong positive correlation between CPI and time and low corresponding p-value for CPI), their inflation does experience a high-degree of irregularity with no consistent increasing or decreasing trend. Given that the core inflation index for CPI-U less food, shelter, and energy *did* pass the statistical test for inflation with a $p < 0.001$, the hypothesis that these resources (food, shelter, and energy) witness price adjustments significantly different from standard inflation rates is confirmed. In calculus terms, the first time-based derivative of $CPI_{F/S/E}$ (which is directly proportional to inflation (i) per the equation: $d(CPI)/dt = i*CPI_o$) is consistently positive (energy being an exception during some time periods). However, the second time-based derivative of CPI ($d^2(CPI)/dt^2 = di/dt*CPI_o$) – the ‘acceleration’ of $CPI_{F/S/E}$ , directly proportional to the ‘rate of change’ or slope of inflation – alternates from positive to negative with strong irregularity.

| | **All Items** | | **All Items Less Food, Energy & Shelter** | | **Food** | | **Shelter** | | **Energy** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **CPI** | **%I** | **CPI** | **%I** | **CPI** | **%I** | **CPI** | **%I** | **CPI** | **%I** |
| **Correlation, r** | 1.00 | -0.42 | 0.99 | -0.72 | 1.00 | -0.37 | 0.99 | -0.45 | 0.94 | -0.03 |
| **p-value** | 7.60E-52 | 2.38E-03 | 1.87E-46 | 2.14E-08 | 4.99E-53 | 7.89E-03 | 7.40E-48 | 1.17E-03 | 2.96E-24 | 8.29E-01 |
| **p < 0.05; p<0.001 (CPI) ; (%I)** | YES | YES | YES | YES | YES | NO | YES | NO | YES | NO |

**Table 2. Pearson product moment correlation test for correlation coefficient, r; and statistical significance test for p < 0.05, p < 0.001, of CPI-U and inflation (%) indices**

Due to the outcomes of this statistical analysis a simple average was determined for food, shelter, and energy, vice calculating a time-dependent equation for each of these factors. Additionally, although the inflation index for “all items less food, energy, and shelter” does show a strong ($p<0.001$) correlation with time, attempts at a best-fit curve to model the time dependency of these data yields $R^2$ values between 0.52 (first-order/linear) and 0.75 (sixth-order polynomial). More importantly, however, is the fact that the best-fit curves do not appear to trend in an expected, or reasonably anticipated, direction. The first-order best-fit curve yields a negatively sloped line that trends towards an inflation value of zero. This curve is discarded for unreasonable inflation forecasting, based on the fact that the entire 49 years worth of historical U.S. CPI data depicts *only* positive for inflation for all items less food, energy, and shelter. Similarly, the fifth and sixth-order best-fit polynomials also beget unreasonable inflation forecasts, being negatively (fifth-order) and positively (sixth-order) sloped in excessive of what could be deemed realistic, given historical CPI data. Due to lack of a suitable best-fit curve to depict the time-dependency of these data, an average will also be used for inflation of all items less food, shelter, and energy. The calculated averages for all factors are depicted in Table 3. Additionally, the correction factors for the improved social discounting equation – %I for $i_1(t)$, $i_2(t)$, $i_3(t)$, and $i_s(t)$ – are given in Table 3.

| | All Items | | All Items Less Food, Energy & Shelter, is(t) | | Food, i1(t) | | Shelter, i2(t) | | Energy, i3(t) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CPI | %I | CPI | %I | CPI | %I | CPI | %I | CPI | %I |
| **AVERAGE:** | 118.2 | 4.4 | 126.4 | 3.907 | 118.2 | 4.416 | 127.6 | 5.039 | 98.8 | 5.728 |

**Table 3. Average CPI & inflation for various product groups, using CPI-U indices (Source: BLS, 2013)**

3. Resource costs for a selection of diminishing (constrained) renewable and non-renewable natural resources (Daly & Farley, 2004):

The two renewable resources chosen for this study are fish and water. The two non-renewable resources chosen are copper and oil. These resources were selected due to their prominence as increasingly constrained, yet highly critical resources, as well as their broad representation of different categories of renewable and non-renewable resources.

Ample information and studies exist, providing evidence of these resources' decline (Stuip, Baker, & Oosterberg, 2002; Whited, Ackerman, & Jackson, 2013; Adams, 2012; Blackman & Baumol, 2008; Venuto, 2012; Patzek & Croft, 2010). However, the exact degree and severity of scarcities were not examined in this study. Refer to Table 4 for the data, including: CPI, inflation-adjusted and normalized CPI data (CPI'), and cost increase rate (%) as a function of time (t).

The Pearson statistical analysis yielded a strong, positive correlation of CPI' with time, indicating that all four renewable and non-renewable costs increased with time, even after adjustment for inflation (refer to Table 5). The p-values for CPI' were less than the alpha value of 0.05, rejecting the null hypothesis with greater than a 99.9% confidence level for all examined resources and confirming this study's hypothesis that the costs of these constrained resources increase with time at a rate greater than inflation (refer to Figure 6). Conversely, the statistical analysis of $i_r$ (cost increase rate (%)) yielded high p-values and therefore failed to reject the null hypothesis. Though predominantly positive, the cost increase rates (or the first time-based derivative of the cost indices) for the scarce resources are not strongly correlated with time. The irregularity of the cost increase rates ($i_r$) is depicted in Figure 7, $i_r$ vs t.

| | | **Renewable Resources** | | | | | | **Non-renewable Resources** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Fish** | | | **Water** | | | **Copper** | | | **Oil** | | |
| **t** | **Year** | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** |
| 0 | 2002 | 188.1 | 1.000 | N/A | 242.5 | 1.00 | N/A | 1559.5 | 1.000 | N/A | 1.2 | 1.0 | N/A |
| 1 | 2003 | 190.0 | 0.988 | -1.2 | 251.7 | 1.01 | 1.5 | 1779.1 | 1.128 | 12.8 | 1.4 | 1.2 | 17.9 |
| 2 | 2004 | 194.3 | 0.984 | -0.4 | 268.1 | 1.05 | 3.8 | 2865.9 | 1.750 | 55.2 | 1.6 | 1.4 | 14.6 |
| 3 | 2005 | 200.1 | 0.980 | -0.4 | 283.4 | 1.08 | 2.2 | 3678.9 | 2.173 | 24.2 | 2.2 | 1.8 | 30.4 |
| 4 | 2006 | 209.5 | 0.994 | 1.4 | 297.2 | 1.09 | 1.6 | 6722.1 | 3.847 | 77.0 | 2.5 | 1.9 | 8.6 |
| 5 | 2007 | 219.1 | 1.011 | 1.7 | 312.6 | 1.12 | 2.3 | 7118.2 | 3.998 | 3.9 | 2.7 | 2.0 | 4.5 |
| 6 | 2008 | 232.1 | 1.031 | 2.0 | 331.3 | 1.14 | 2.1 | 6955.9 | 3.727 | -6.8 | 3.8 | 2.7 | 35.1 |
| 7 | 2009 | 240.6 | 1.073 | 4.0 | 354.4 | 1.23 | 7.4 | 5149.7 | 2.769 | -25.7 | 2.5 | 1.8 | -32.8 |
| 8 | 2010 | 243.2 | 1.067 | -0.5 | 380.7 | 1.30 | 5.7 | 7534.8 | 3.986 | 44.0 | 2.9 | 2.1 | 14.6 |
| 9 | 2011 | 260.5 | 1.108 | 3.8 | 402.9 | 1.33 | 2.6 | 8828.2 | 4.528 | 13.6 | 3.7 | 2.6 | 22.9 |
| 10 | 2012 | 266.7 | 1.111 | 0.3 | 428.6 | 1.38 | 4.2 | 7962.3 | 4.001 | -11.6 | 3.8 | 2.5 | -1.0 |
| **AVERAGE:** | | 222.2 | 1.031 | **1.1** | 323.0 | 1.157 | **3.3** | 5468.6 | 2.991 | **18.6** | 2.6 | 1.9 | **11.5** |
| **a:** | | 0.303 | | | 0.908 | | | 0 | | | 5.274 | | |
| **Weighted Avg:** | | **2.762** | | | | | | **11.477** | | | | | |
| | | **9.850** | | | | | | | | | | | |

**Table 4. Scarce resource CPI and cost increase, Ir (%), versus time, t (Source: BLS, 2012a; BLS, 2013; Mongabay, 2013)**

NOTE: CPI' = CPI adjusted for inflation using 2013 dollars and given as a ratio of 2002 inflation-adjusted values

| | **Fish** | | | **Water** | | | **Copper** | | | **Oil** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** | **CPI** | **CPI'** | **Ir (%)** |
| **Correlation, r** | 0.99 | 0.91 | 0.51 | 0.99 | 0.97 | 0.48 | 0.90 | 0.86 | -0.42 | 0.91 | 0.87 | -0.27 |
| **p-value** | 0.000 | 0.000 | 0.128 | 0.000 | 0.000 | 0.150 | 0.000 | 0.000 | 0.221 | 0.000 | 0.000 | 0.440 |
| **p < 0.05; p < 0.001 (CPI) ; (Ir)** | YES | YES | NO | YES | YES | NO | YES | YES | NO | YES | YES | NO |
| **STD DEV** | N/A | N/A | 1.84 | N/A | N/A | 1.93 | N/A | N/A | 32.00 | N/A | N/A | 19.11 |

**Table 5. Pearson product moment correlation test for correlation coefficient, r; statistical significance test for p < 0.05, p < 0.001; and Standard Deviation calculation of cost and cost-increase indices for scarce resources**

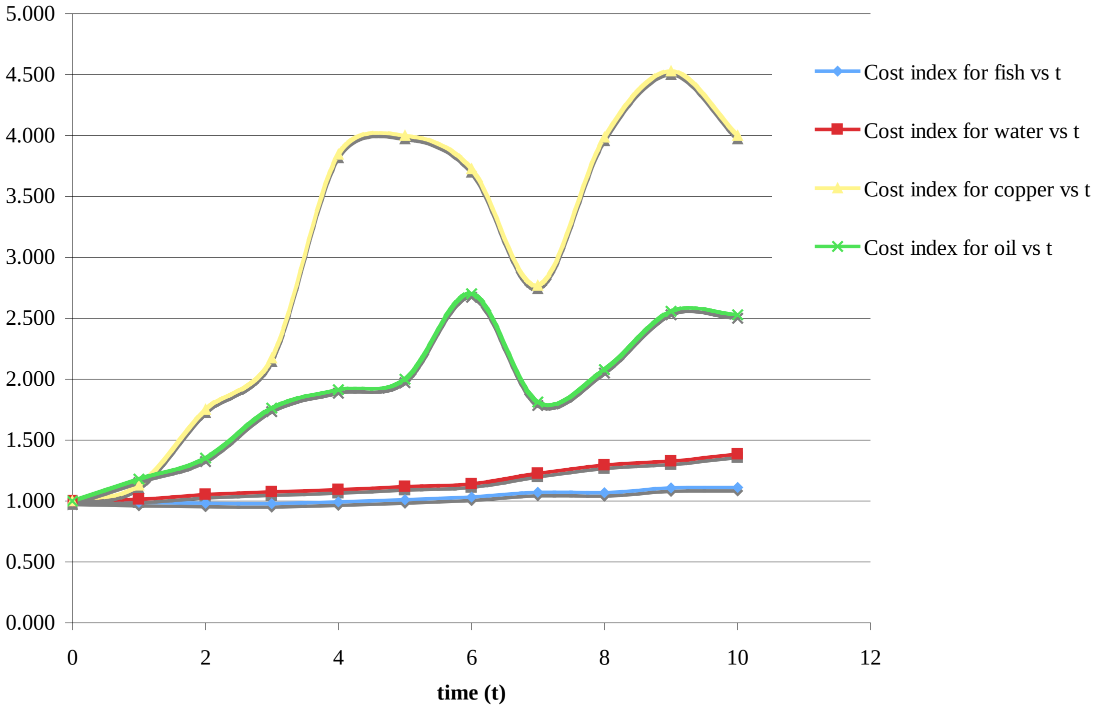

**Figure 6. Inflation-adjusted cost indices vs time (t) for renewable and non-renewable resource samples, 2002-2012**

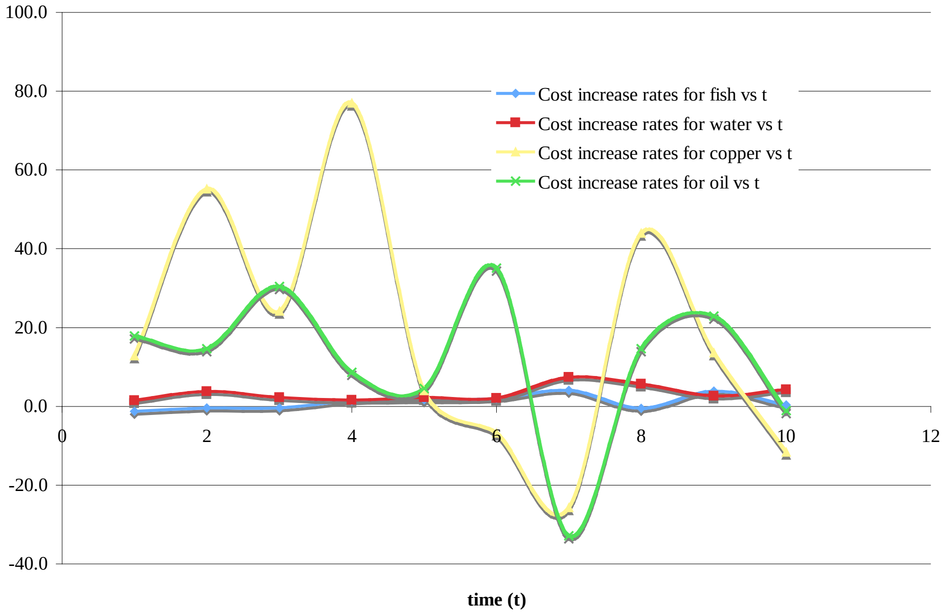

**Figure 7. Cost increase rates, $i_r$ (%), vs time (t) for renewable and non-renewable resource samples, 2002-2012**

Given the lack of time-dependence of $i_r$, the values were averaged using weighted ratios, a, based on their "relative importance of components in the Consumer Price Indexes" data (BLS, 2012) (Refer to Table 4). Copper was given a weighted importance of 0, due to its purchase quantity being negligible to most urban consumers and thus not directly reflected in the BLS's 'relative importance' index.

The correction is given as: $i_r(t) = 9.850$. However, if copper and oil are excluded for excessive standard deviation (or dispersal of data from the mean), the correction factor will be: $i_r(t) = 2.762$. (Refer to Table 5 for standard deviations, calculated as 32.0 and 19.11 for copper and oil, respectively). The high volatility of copper and oil prices is largely the result of geopolitical dynamics and demand-side pricing volatility, vice supply-side constraints (Kilian, 2013; Srinivas, 2011). Therefore, oil and copper price trends derived from supply-side resource constraints are likely overshadowed by these other confounding factors. In the absence of a comprehensive examination of the distinct causal association between supply-side constraints and prices – exclusive of geopolitical and demand-side influences – it is appropriate to consider scarcity-derived cost increases both with and without copper and oil. The recommendations section addresses this in more detail.

4. The relative socio-economic valuation ratio of holding resource investments to financial instruments, $f_v(t)$, versus time (t):

The following data were interpreted as resource-based investments (vice financial investments): Expenses towards owned dwellings (payments towards principle); mortgage interest and charges; property taxes; and maintenance, repairs, insurance, and other expenses

(BLS, 2012b). All of these fees were considered to be resource-based investments associated with home and land ownership. Additionally, because owner-occupied home payments offset rent costs, this study also subtracted mean rental costs from the aforementioned resource investment totals to determine a ‘net resource investment’ total.

The following data were interpreted as financial investments: Personal insurance and pensions; life and other personal insurance; and pensions and social security (BLS, 2012b). Because data for ‘personal insurance and pensions’ shares significant overlap with ‘pensions and social security’, these two data were averaged for each age group before being added to ‘life and other personal insurance’ to determine a total financial investment number. This number was then divided into the net resource investment (R) to get the ratio R / F, which was plotted against the time in years to average U.S. life expectancy, t (t = 79 minus the average age for the specific investment data point) (refer to Table 6).

The relationship between R / F and time (to average U.S. life expectancy) indicated a strong negative correlation on the Pearson correlation test and the null hypothesis was rejected with a nearly 99.75% confidence level. These data support the hypothesis that money is not viewed as perfectly substitutable for resources in the mid to short term, resulting in the overvaluing of social discount rates for the approximate timeframe $0 < t < 40$. A fifth order best-fit polynomial curve with an R2 of 0.9997 was resolved to estimate the time-dependent correction factor, $f_v(t)$, for the improved social discount rate (refer to Figure 8):

$$f_v(t) = 2E\text{-}07t^5 - 2E\text{-}05t^4 + 0.0008t^3 - 0.0038t^2 - 0.3527t + 6.3218$$

This correction function is limited in that it only follows the asymptotically decreasing R / F value until $t \sim 21$, after which the function begins to increase again and deviate from the generally decreasing trend for R / F. Therefore, this correction function would be accurate for short to mid-term environmental discounting applications only. For long term, multi-generational functions, the average R / F value should instead be used for $f_v(t)$.

$$f_v(t) = 2.0476$$

For simplicity, this study will also use the average R / F value in its combined analysis of all proposed social discount correction factors.

| Age | time (t) | Resources (R) | Financial (F) | fv(t) (R/F) |
|---|---|---|---|---|
| 77 | 2 | 5899 | 1051 | 5.61 |
| 70 | 9 | 10384 | 3146 | 3.30 |
| 60 | 19 | 12194 | 7346.5 | 1.66 |
| 50 | 29 | 12538 | 8418.5 | 1.49 |
| 40 | 39 | 11662 | 7196 | 1.62 |
| 30 | 49 | 3501 | 5385 | 0.65 |
| 21.5 | 57.5 | 0 | 2364 | 0.00 |
|  |  |  | **AVERAGE** | **2.0476** |

**Table 6. The relative socio-economic valuation of resource investments to financial investments, fv(t), vs t (Source: BLS, 2012b)**

|  | **R/F Ratio** |
|---|---|
| **Correlation, r** | -0.90 |
| **p-value** | 0.003 |
| **p < 0.05** | 🟩 YES |

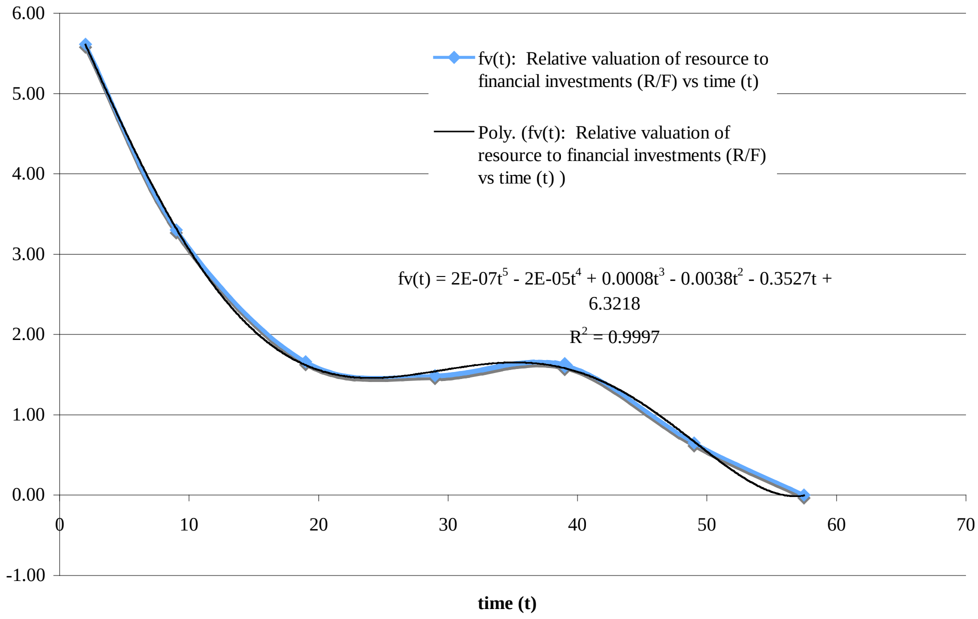

**Figure 8. Relative valuation of resource to financial investments (fv(t) = R(t)/F(t)), vs time to average U.S. life expectancy (t)**

5. Intergenerational valuation as a function of time (from a datum of t = 0 = present time), based on real per-capita GDP versus t, $g_v(t)$:

The real per-capita GDP data from 1950 to 2010 (with interpolated data entered for 2020) is depicted in Table 7. The generational averages of these data and the future-to-present ratios ($g_v(t) = (GDP/pop)_n / (GDP/pop)_0$) of these generational averages were calculated and analyzed for correlation with time. Both real per-capita GDP and $g_v(t)$ displayed a strong, positive correlation with time and passed the p-tests for significance with high confidence levels. The positive relationships of both GDP and $g_v(t)$ vs time are depicted in Figures 9 and 10.

**Real (inflation-adjusted) GDP data**

| time (t) | Year | GDP (trillion $) | pop | GDP/pop | Decade | Avg GDP/pop | m |
|---|---|---|---|---|---|---|---|
| 0 | 1950 | 2.18 | 151868000 | 14367 | N/A | N/A | N/A |
| 10 | 1960 | 3.11 | 179979000 | 17256 | 1950 - 1970 | 18250 | N/A |
| 20 | 1970 | 4.72 | 203984000 | 23128 | 1960 - 1980 | 22914 | 587.1336639 |
| 30 | 1980 | 6.44 | 227224681 | 28357 | 1970 - 1990 | 29107 | 522.9160426 |
| 40 | 1990 | 8.95 | 249622814 | 35836 | 1980 - 2000 | 36241 | 747.8712085 |
| 50 | 2000 | 12.57 | 282162411 | 44532 | 1990 - 2010 | 42715 | 869.6132961 |
| 60 | 2010 | 14.78 | 309330219 | 47779 | 2000 - 2020 | 48816 | 324.6913981 |
| 70 | 2020 | N/A | 336835531 | 54139 | N/A | N/A | N/A |

| | | | to = 1960 | to = 1970 | to = 1980 | to = 1990 | to =2000 |
|---|---|---|---|---|---|---|---|
| **time (t)** | **Decade** | **Avg GDP/pop** | **gv(t)** | **gv(t)** | **gv(t)** | **gv(t)** | **gv(t)** |
| 10 | 1950 - 1970 | 18250 | 1.00 | N/A | N/A | N/A | N/A |
| 20 | 1960 - 1980 | 22914 | 1.26 | 1.00 | N/A | N/A | N/A |
| 30 | 1970 - 1990 | 29107 | 1.59 | 1.27 | 1.00 | N/A | N/A |
| 40 | 1980 - 2000 | 36241 | 1.99 | 1.58 | 1.25 | 1.00 | N/A |
| 50 | 1990 - 2010 | 42715 | 2.34 | 1.86 | 1.47 | 1.18 | 1.00 |
| 60 | 2000 - 2020 | 48816 | 2.67 | 2.13 | 1.68 | 1.35 | 1.14 |
| | **AVERAGE:** | 33007 | 1.81 | 1.57 | 1.35 | 1.18 | 1.07 |
| | **Correlation, r** | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | **p-value** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | **$p < 0.05$** | YES | YES | YES | YES | YES | YES |

**Table 7. Intergenerational valuation, gv(t), vs time (t), based on per-capita real GDP (Source: BLS, 2013; BEA, 2013; U.S. Census Bureau, 2012; The World Bank Group, 2013; Trading Economics, 2013)**

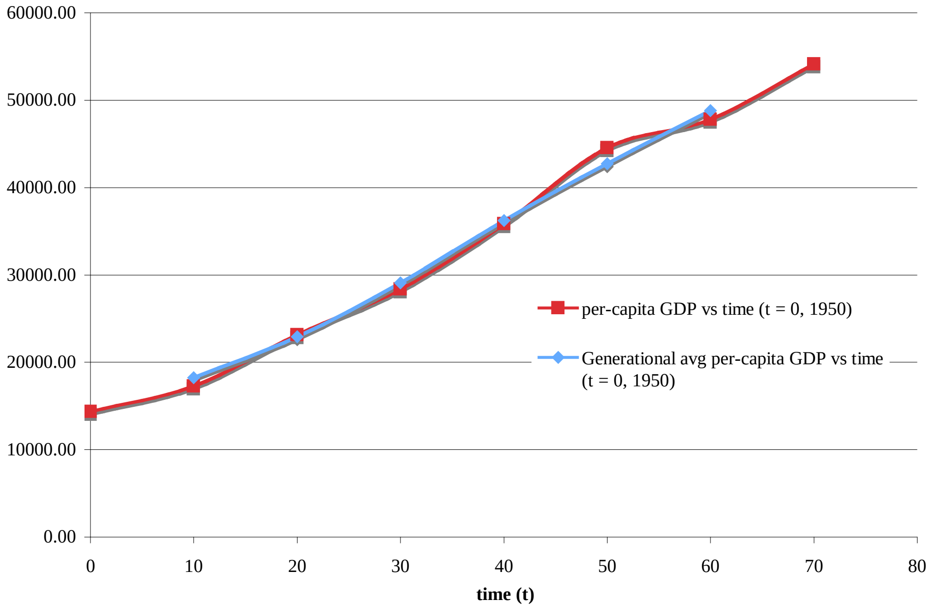

**Figure 9. Per-capita real GDP and generational average per-capita real GDP vs time (t)**

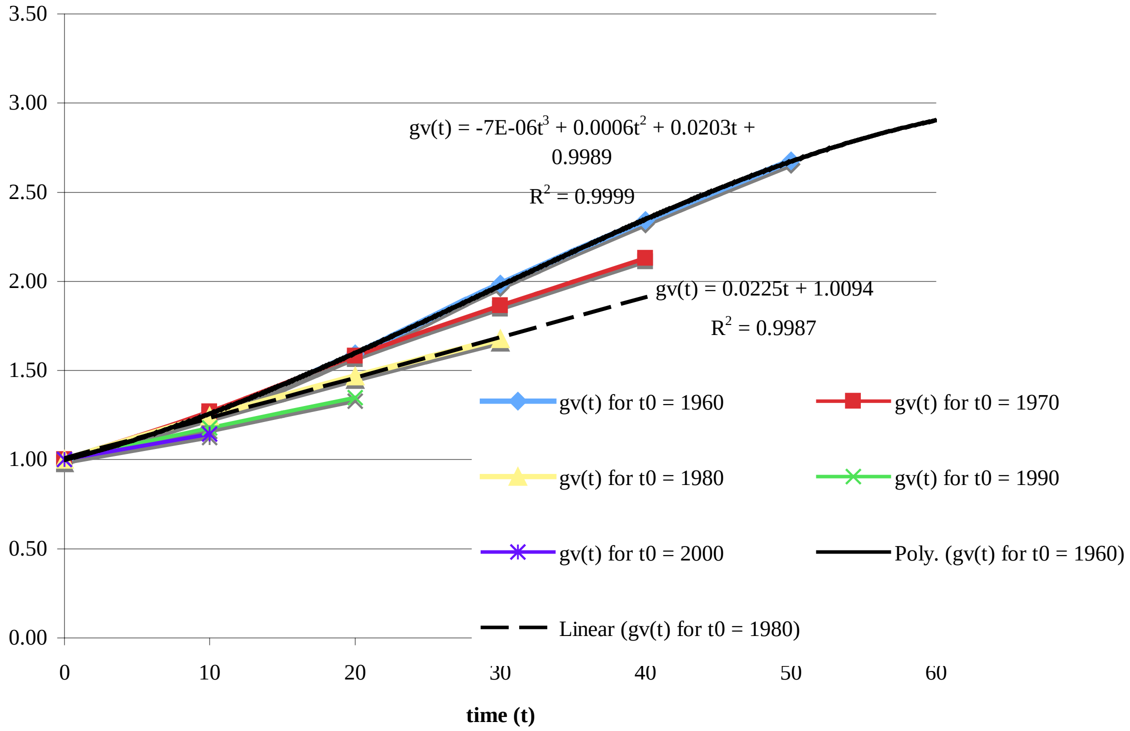

**Figure 10. gv(t) for t0 = 1950 - 2000**

The high correlation and low p-value of $g_v(t)$ demands a best-fit function to solve for the time-dependent correction factor. Though the $g_v(t)$ curves for $t_0$ = 1980, 1990, and 2000 are arguably the most representative of present-day intergenerational GDP ratios, the $g_v(t)$ data for $t_0$ = 1960 was used to determine the social discount rate correction factor for several reasons:

a. This data set, representing 1950 through 2020, is the most comprehensive of all five examined, adding to the reliability of the resultant $g_v(t)$ correction factor.

b. This data set, representative of *historical* trends, adheres to the descriptive (data-driven) approach utilized in this study to improve social discount rates for environmental conservation.

c. This data set yields a best-fit curve (third-order polynomial) with both a very high $R^2$ value and a realistic trend line that values future generations at decreasing rates after t ~ 71. This compared to the other four data sets, which yield constantly increasing valuation ratios (an unrealistic forecast model that would, in turn, yield infinitely large present day values for any long term action).

The social discount rate correction factor for intergenerational valuations is given as:

$$g_v(t) = -7E\text{-}06t^3 + 0.0006t^2 + 0.0203t + 0.9989$$

Ultimately, when applied to this study's proposed modified discounting equation, this neoclassical method of using real per-capita GDP growth to determine intergenerational valuation begets an effect on social discount rates (decreasing them and motivating environmental action for future generations) *opposite* the marginal utility correction that is popularly applied by economists to offset the increasing wealth of future generations. The result is that social discount rates are reduced (or are 'mitigated') by increasing amounts with respect to time, until t ~ 71, at which time this intergenerational mitigating effect stabilizes and thereafter lessens (resulting in discount rates that are reduced by decreasing amounts with time).

*Cumulative Effect of All Correction Factors*

The proposed modified discounting method is reviewed below:

$$PV=\sum FV/(1+ r')^t$$

The modified social discount rate, r', attempts to correct for intergenerational and ecological inequity of environmental benefits by accounting for current monetary and resource dynamics, resource vs. monetary substitutability, and intergenerational valuations:

$$r' = \{1 / [g_v(t) * f_v(t)]\} \times [r – i']$$

$$\text{where } i' = {}_{p=1}\Sigma^n \, [i_p(t) * (a_p/K)] + i_s * (a_s/K) + i_r(t)$$

r = 0.07, the standard investment interest rate used by the EPA and OMB (EPA, 2007; Arrow et al., 2013)

CORRECTION FACTORS:

1. Standard inflation rate (less food, shelter, energy)

   $i_s(t) = 0.03907$

2a. Resource cost-increase (inflation) rates for food, shelter, and energy, $i_p$ (refer to Table 3):

   $i_1(t)$ (food) = 0.04416

$i_2(t)$ (shelter) = 0.05039

$i_3(t)$ (energy) = 0.05728

2b. Weighted consumption ratios, a (refer to Table 8):

$a_1 = 14.312$

$a_2 = 31.681$

$a_3 = 9.561$

$a_s = 44.446$; $\{K - {}_{p=1}\Sigma^n [a_p]\}$

K = 100; $\{{}_{p=1}\Sigma^n [a_p] + a_s = 100$ by convention (BLS, 2012a)$\}$

| | All Items = K | All Items Less Food, Energy & Shelter, as | Food, a1 | Shelter, a2 | Energy, a3 |
|---|---|---|---|---|---|
| **a:** | 100 | 44.446 | 14.312 | 31.681 | 9.561 |

**Table 8. Weighted consumption ratios, a, from the ÒRelative importance of components in the Consumer Price IndexesÓ, December 2012 (Source: BLS, 2012a)**

3. Inflation-adjusted cost-increase for supply-constrained resources, with respect to time, $i_r(t)$, examined for three different data scenarios (refer to Table 4):

$i_{r1}(t) = 0.09850$ (excluding copper due to negligible consumption weight);

$i_{r2}(t) = 0.02762$ (excluding copper and oil, due to excessive standard deviation of data from the mean)

$i_{r3}(t) = 0$ (excluding all cost increase data for supply-constrained resources due to lack of group data robustness)

4. Resource-to-financial ($f_v$) valuation ratio:

$f_v(t) = 2.0476$

5. Future-to-present intergenerational ($g_v$) valuation ratio:

$$g_v(t) = -7E\text{-}06t^3 + 0.0006t^2 + 0.0203t + 0.9989$$

| | | | |
|---|---|---|---|
| **ir(t):** | 0.0985 | 0.02762 | 0 |
| | i' | i" | i"' |
| | 0.1436 | 0.0727 | 0.0451 |
| | r' = {1 / [gv(t) * fv(t)]} x [r Ğ i] | | |

| t | r | r' | r'' | r''' | f(t) | g(t) |
|---|---|---|---|---|---|---|
| 0 | 0.07 | -0.0360 | -0.0013 | 0.0122 | 2.0476 | 0.9989 |
| 1 | 0.07 | -0.0353 | -0.0013 | 0.0119 | 2.0476 | 1.0198 |
| 2 | 0.07 | -0.0345 | -0.0013 | 0.0117 | 2.0476 | 1.0418 |
| 3 | 0.07 | -0.0338 | -0.0013 | 0.0114 | 2.0476 | 1.0650 |
| 4 | 0.07 | -0.0330 | -0.0012 | 0.0112 | 2.0476 | 1.0893 |
| 5 | 0.07 | -0.0323 | -0.0012 | 0.0109 | 2.0476 | 1.1145 |
| 6 | 0.07 | -0.0315 | -0.0012 | 0.0106 | 2.0476 | 1.1408 |
| 7 | 0.07 | -0.0308 | -0.0011 | 0.0104 | 2.0476 | 1.1680 |
| 8 | 0.07 | -0.0301 | -0.0011 | 0.0102 | 2.0476 | 1.1961 |
| 9 | 0.07 | -0.0294 | -0.0011 | 0.0099 | 2.0476 | 1.2251 |
| 10 | 0.07 | -0.0287 | -0.0011 | 0.0097 | 2.0476 | 1.2549 |
| 11 | 0.07 | -0.0280 | -0.0010 | 0.0095 | 2.0476 | 1.2855 |
| 12 | 0.07 | -0.0273 | -0.0010 | 0.0092 | 2.0476 | 1.3168 |
| 13 | 0.07 | -0.0267 | -0.0010 | 0.0090 | 2.0476 | 1.3488 |
| 14 | 0.07 | -0.0260 | -0.0010 | 0.0088 | 2.0476 | 1.3815 |
| 15 | 0.07 | -0.0254 | -0.0009 | 0.0086 | 2.0476 | 1.4148 |
| 16 | 0.07 | -0.0248 | -0.0009 | 0.0084 | 2.0476 | 1.4486 |
| 17 | 0.07 | -0.0242 | -0.0009 | 0.0082 | 2.0476 | 1.4830 |
| 18 | 0.07 | -0.0237 | -0.0009 | 0.0080 | 2.0476 | 1.5179 |
| 19 | 0.07 | -0.0232 | -0.0009 | 0.0078 | 2.0476 | 1.5532 |
| 20 | 0.07 | -0.0226 | -0.0008 | 0.0076 | 2.0476 | 1.5889 |
| 21 | 0.07 | -0.0221 | -0.0008 | 0.0075 | 2.0476 | 1.6250 |
| 22 | 0.07 | -0.0216 | -0.0008 | 0.0073 | 2.0476 | 1.6614 |
| 23 | 0.07 | -0.0212 | -0.0008 | 0.0072 | 2.0476 | 1.6980 |
| 24 | 0.07 | -0.0207 | -0.0008 | 0.0070 | 2.0476 | 1.7349 |
| 25 | 0.07 | -0.0203 | -0.0008 | 0.0069 | 2.0476 | 1.7720 |

**Table 9. Modified social discount rates, rÕ, given ir(t) = 0.09850, 0.02762, and 0**

Independently, this study's data (for each correction factor that contributes to the aforementioned modified social discount rate, r') affirmed all of the proposed sub-hypotheses. A summary of this study's hypotheses and findings are:

Hypothesis 1: Monetary inflation rates, $i_s(t)$, for the U.S. Dollar have remained consistently positive, yielding overvalued discount rates over the examined timeframe (46 years from 1967 through 2012).

Finding: Per this study, the CPI for all items less food, shelter, and energy increases consistently with time, indicating a consistently positive value for $i_s(t)$, averaging 3.907%.

Hypothesis 2: Many goods and services experience price adjustments different from standard inflation rates due to other distinct market dynamics (dissociated from the monetary influences that drive inflation). Such price adjustments, if greater than average inflation rates, yield further-overvalued discounting rates, and may have a time-dependency that is different from goods subject to standard inflation rates (in #1 above).

Finding: This study determined that the inflation rates for food, shelter, and energy are significantly greater than that of $i_s(t)$, at 4.416%, 5.039%, and 5.728% respectively.

Hypothesis 3: Natural resource scarcities have yielded cost increases that may further overvalue discount rates as applied to over-harvested/constrained resources.

Finding: The inflation-adjusted cost increase rates of both renewable and non-renewable resources is determined to be 9.850% (geopolitical and demand-based influences notwithstanding); the inflation-adjusted cost increase rates of renewable resources averages 2.762%. As inflation-adjusted metrics, both of these numbers indicate that these scarce resources harbor cost increases that are *greater* than standard inflation rates.

Hypothesis 4: Prevailing discounting methods assume that money is perfectly substitutable for future resources, giving equal preference towards present-day financial investments in lieu of present-day actions that bear future resource and ecological yields. This ‘equal substitutability of money for resources’ may not be accurate based on objective or empirical market standards and *may* overvalue discounting rates if market realities reflect a preference for investment in resources over financial instruments.

Finding: Neoclassical economic data for resource versus financial-based investments indicates that people prefer resource investments to financial instruments at a ratio of over 5-to-1, decreasing as time (remaining to the age of average U.S. life expectancy) increases until t ~ 45, when the neoclassical preference begins to reverse in favor of financial-based investments for t > 45. Over the entire timeline of the U.S. average life expectancy, however, the average ratio of resource-to-financial investment preferences is 2.0476-to-1. Thus, on average, money has less-than 50% substitutability for resources, vice the 100%/perfect substitutability assumed via prevailing discounting methods.

Hypothesis 5: Prevailing discounting methods do not account for our valuation of future generations. If such valuations of future generations (as a ratio of our valuation of current generations) are other than unity, current discounting methods risk unnecessarily moderating social discount rates.

Finding: Relative valuation of future generations, per neoclassical economic data (using per-capita GDP) is greater than one and increases with time until t ~ 71.

These findings universally affirm this study's hypotheses that conventional discount rates are overvalued, due to lack of consideration for the aforementioned neoclassical economic factors. Moreover, applying the quantitative corrections for these factors yields a modified discount rate that more accurately represents applicable neoclassical principles and yields the modified discounting rates, r', depicted in Table 9 (with respect to t). Three scenarios for $i_r(t)$ were analyzed, resulting in three separate modified discount rates, r', r'', and r'''. As can be viewed in Table 9, the modified discount rates r', and r'' (accounting for the scarcity-based cost increases of all resources and renewable resources, respectively) are both negative and increase (become less negative) with time. Conversely, the modified discount rate r''' (which excludes cost increase data for scarce resources entirely) begets a relatively low interest rate of 1.22% at time t = 0 and decreases towards a minimum of 0.41% until t ~ 71, at which time the interest rate begins to increase again until it reaches a maximum of 10.6% at t = 119 (before decreasing yet again). The variability of the discount rate is due to the third-order polynomial curve that is used by this study to define $g_v(t)$. Given that $g_v(t)$ was determined using data for t = 0 through 70 and plotted for intergenerational t values of 0 through 60, the best fit curve $g_v(t)$ reasonably approximates the data until just before $g_v(t)$ reaches its minimum at t ~ 71. After this point, however, the equation used for $g_v(t)$ (and consequently this study's values for r', r'', and r''') is spurious.

## VI. DISCUSSION

### *Implications of Modified Social Discount Rates, r', r'', r'''*

This study examined the hypothesis that contemporary social discounting methods contribute to the degradation of natural resources and global sustainability. One of the most widely recognized and contentious shortcomings of contemporary discounting methods is the fact that it leverages a fixed (and typically high 3 to 7%) rate. This catalyzes the exponential decline of the present values for any future ecological benefit or resource, with respect to t, and reduces the price-competitiveness of any future ecological or resource yield in a cost-benefit analysis. The result is a strong partiality towards present day benefits and a disincentive for conservation or environmental actions for future generations.

In quest for a descriptive solution to the dilemma of overvalued, fixed discount rates, this study devised a modified discount equation and explored pertinent correction factors derived from neoclassic economic metrics. Ultimately, this study's modified discount equation (using neoclassical correction factors) demonstrates that neoclassical economics *can* provide a viable means to improve the social discount rate for ecological conservation and sustainability.

As depicted in Figures 11 and 12, this study's modified social discount rates (r', r'', and r''') result in equivalent present values that are significantly greater than those calculated using the contemporary discount rate of r = 0.07. As an example, the *positive and time-dependent* modified discount rate of r''' yields an equivalent present value of $843 for an ecological benefit valued at $1000 in 25 years; whereas the contemporary discount rate of 7% yields a much smaller equivalent present value of $184. The economic 'competitiveness' of this $1000, 25-year ecological action is significantly greater under the modified social discount method proposed by this study using neoclassical principles. Additionally, because the absolute value of the modified social discount rates (r', r'', r''') become smaller with time, this study's modified social discounting mitigates the exponential decrease/increase in equivalent present values. In this sense, this study’s modified social discount rates provide a stabilizing feature in comparison to the fixed discount rates currently used in environmental economics.

Interestingly, the social discount rates calculated for r’ and r’’ (considering renewable/non-renewable and renewable-only resource scarcities) imply that any resource or ecological good conserved for future generations is worth *more* in equivalent present dollars than in calculated in future worth (assuming that the calculated future worth does not already account for projected scarcities). This promotes maximum conservation of resources that are, themselves, facing scarcity. However, negative discount rates also de-motivate actions for present generations, when such actions undermine the conservation of future resources. As a result, the negative discount rates for r’ and r’’ can actually risk impoverishing present generations in the interest of ecological sustainability and resource conservation. Consequently, these negative discount rates, which incorporate the ‘scarcity-based cost increase correction factor’, *must* be applied *only* to decisions that affect constrained resources. Additionally, as the resources-in-question recover (as promoted through the application of these modified discount rates), the discount rate must be modified with a new, commensurate correction factor for $i_r(t)$.

The social discount rate for r’’’, conversely, does not account for scarcity-based cost increases and upholds a small and positive, but decreasing, discount rate. This ensures that equivalent present values are relatively high, though still slightly lower than future values. The result of this quantitative dynamic is that future ecological benefits are more cost-competitive than through contemporary discount rates, but without risking complete substitution of present day needs for future conservation and sustainability, as negative social discount rates might.

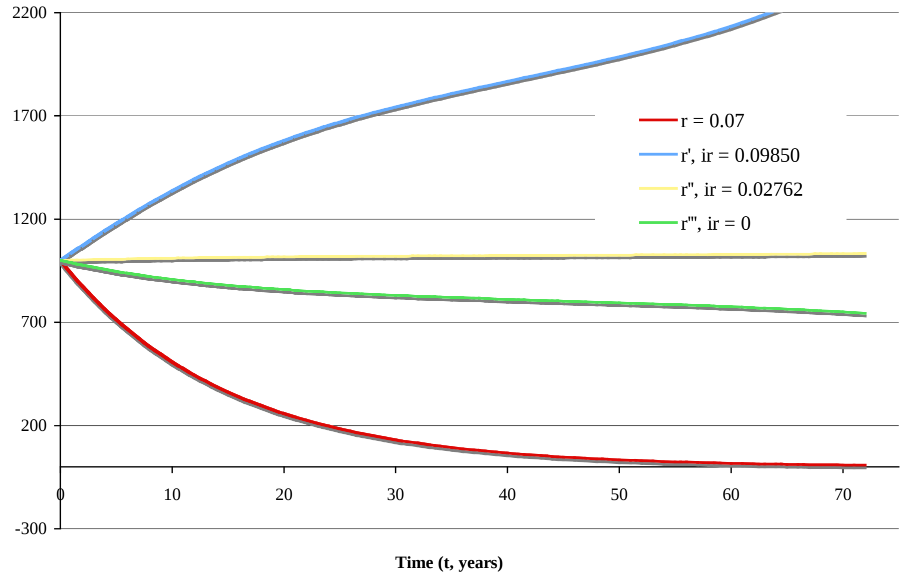

**Figure 11. Present Value (PV) vs. time (t), given a one-time Future Value (FV) of $1K a
time (t) and using the modified social discount rate, r'**

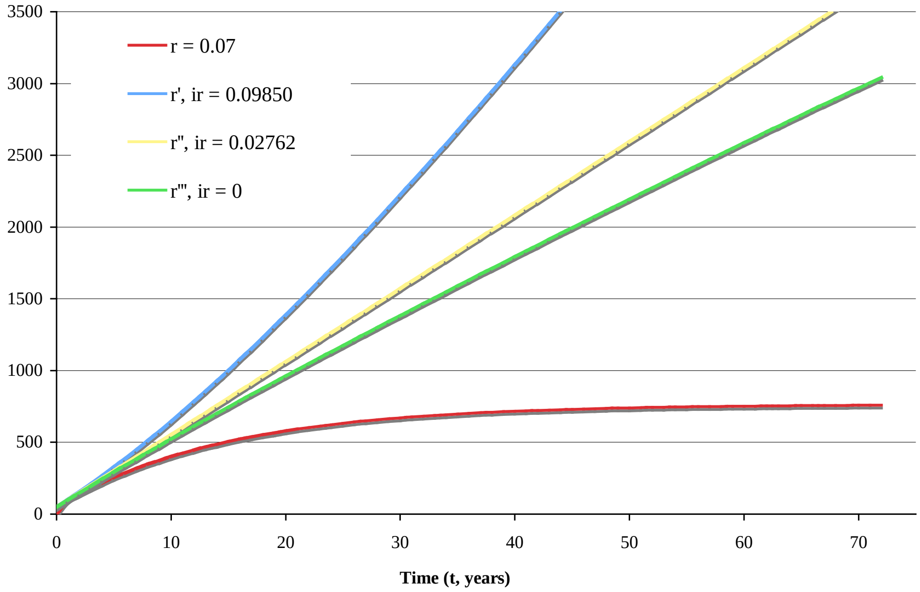

**Figure 12. Present Value (PV) vs. time (t), given $50 in Future Value (FV) achieved each
subsequent year until time (t) and using the modified social discount rate, r'**

### *Comparing the Normative and Positive Approaches*

This study's descriptive, neoclassical approach at modifying the social discount rate delivers a promising improvement for ecological sustainability and the management and conservation of natural resources, and especially scarce resources, for future generations. It is critical to note, however, that the methods used in this study to modify the social discount rate are positive – they are derived from existing data, vice any intended outcome. Consequently, the results of the modified social discounting equation is a function of *both* accounting for economic realities that are normally ignored in contemporary discounting, as well as the empirical data of such economic realities. Given that the latter of these two factors is largely *coincidental* in its ability to lower and/or decrease social discount rates, the 'ecological success' of the modified discounting equation is coincidental as well. As an example, if per-capita GDP begins to decrease *and* people shift their expenditures away from resources and towards financial instruments (an admittedly unlikely combination), the modified social discount rate would increase, effectively de-motivating conservation and sustainability regardless of ecological need.

Though this study provides a simplistic and effective improvement to current social discount rates using prevailing neoclassical principles, this method is not without flaw. To avoid the inherent risk of this, or any positive method's, data-driven outcomes, a normative approach would be required instead. A normative approach at social discounting calculates the discount rate that is appropriate given an intended resource outcome. One example is the 'Green Golden Rule' touted by Betratti et al. (1993), which uses a combination of resource logistics (or growth rate) curves and consumption rates to calculate an optimal utility function and an appropriate social discount rate for achieving maximum sustainable yield of a resource.

### *Summary*

Global resource extraction and consumption rates have reached largely unsustainable levels and risk compromising future generations' living standards and even their survivability. Such resource challenges demand aggressive and time-dependent resource management methods that promote sustainability and ecological conservation, for the well being of future generations. Contemporary neoclassical economics manage resource allocation and production largely based upon present quantities and abilities to maximize present benefits. Additionally, when accounting for a time variable through intertemporal discounting, contemporary social discounting methods demonstrate significant deficiencies in achieving intergenerational equity and ecological resource sustainability due to the relatively high, fixed discount rates commonly used. Such discount rates yield an exponential decrease in equivalent present-day values of future ecological or resource benefits.

This study examined modifying the social discount rate through a simple, descriptive approach that uses neoclassical economic principles and metrics. In its modified discounting equation, this study examined several important economic variables that are absent from consideration in contemporary discounting. These variables include inflation, other-than inflationary cost increases, resource scarcity cost increases, resource versus monetary valuation ratios, and intergenerational valuation ratios. By examining these variables in the context and framework of neoclassical economics, this study accomplished two important ends:

1. It corrected for economic deficiencies in contemporary discounting methods;

*and*

2. It achieved reduced social discount rates, thereby favoring resource conservation and proactive environmental efforts that promote ecological sustainability and resource availability for future generations.

Most importantly, this study accomplished the two aforementioned goals using the existing neoclassical economic framework of the developed and globalized world as the overarching guiding principle. In doing so, this study demonstrated the feasibility of bolstering U.S. stewardship of both the environment and of future generations through a more comprehensive accountancy of existing empirical data, and without requiring a shift of the prevailing international economic paradigm.

### *Recommendations*

### *Improving the Positive Approach to Modified Social Discounting, using the Neoclassical Framework:*

Hypotheses 1 and 2: The high irregularity of year-to-year inflation rates placed the development of a time-dependent modeling function outside the scope of this study. However, this study did conduct a cursory analysis of compound energy inflation rates for the entire examined time period to determine the effect on inflation volatility. Using the compound interest and discount rate equation ($PV = FV/(1+r)^t$) in lieu of the simple inflation calculation (which was used to determine year-to-year inflation rates in this study $\{[CPI_1\text{-}CPI_0]/CPO_0\}$), this study conducted a cursory examination of the effective compounded inflation rates. By rearranging the discounting equation, the compound inflation rate is determined as: $r = [(FV/PV)^{(1/t)} – 1]$. Simply put, these are the inflation rates that would yield the CPI value at any given time, $t = x$, using the CPI at $t = 0$ (vice at the prior year of $t = x-1$) as the entering argument. The compound inflation rates were calculated using both the starting year (1963, $t = 0$) in the data set as the starting point for determining compound inflation rates (r); and by using the ending year (2012, $t = 49$) as the starting point in the compound inflation calculation to determine the compound inflation rates (r') (refer to Table C in Appendix C**)**. The former method (r) yields improved inflation rate stability as t increases, while the latter (r') method causes inflation rate stability to start high and decrease over time (refer to Figure C in Appendix C). Both methods yield slightly different average inflation rates over the entire time period. Statistical analysis indicates that the correlation coefficient for the compound interest rates with $t = 0$ as the start (r) is significantly stronger than that of the year-to-year inflation values ($i_3$). Moreover, the p-test for significance yields a much higher confidence level for compound interest rates with $t = 0$ as the start, exceeding the p-test alpha value of $p < 0.05$, and almost passing the p-test for an alpha value of 0.001. Conversely, the (absolute value) correlation coefficient and p-test for significance with $t = 49$ as the start yield nearly identical results to that of the year-to-year inflation rates – including a weak correlation and a p-value well greater than 0.05 (refer to Table CC in Appendix C).

Given these findings, compound inflation rates should be calculated for all factors failing the p-test for significance (food, shelter, energy, and inflation-adjusted cost-increases due to resource scarcities) using the starting date (e.g. 1963) as $t = 0$. If the p-test for significance (second-order, $p < 0.001$) passes, then the null hypothesis of zero time-dependence is rejected and the compound inflation data should be analyzed for time-dependence. The resulting best-fit curve of compound inflation (vs. t) should be used (vice an average inflation rate) in the modified discounting equation.

Hypothesis 3: Resource scarcities and their cost-dependent impact on this study's modified social discount equation should be investigated using a more complete data set of constrained resources. This will enable several factors to be quantified: Current resource extraction rate and quantity as a percentage of peak quantity (for nonrenewable resources that have exceeded 'peak production'); current resource extraction rate and quantity as a percentage of maximum renewal quantity (for renewable resource quantities with logistics curves that are below the quantity at which maximum renewal or reproduction rate is achieved); resource extraction rates versus time; and resource cost versus extraction rates and time. A correlation or multiple regression analysis should be conducted between resource quantity/scarcity level, extraction rate, and time, to determine the strength of correlation between these three variables. Additionally, a multiple regression analysis should be conducted to determine the strength of correlation between cost and the independent variables of time and resource extraction rates in order to determine correlation and control for influences such as demand, technology fluxes, and geopolitical dynamics. Cost data that bares a strong positive correlation with time and a strong negative correlation with resource extraction rates should be investigated for inclusion into a 'resource scarcity' correction factor, to adjust the social discount rate.

Hypothesis 4: The ratios of resource-based versus financial investments used in this study empirically reflect society's relative, time-dependent preference for resources over money, and therefore provide a reasonable estimation of the substitutability (or lack thereof) of money for resources. However, these data do not fully and perfectly reflect society's willingness to pay for natural resource conservation and protection and other means of begetting intergenerational benefits. Further studies are needed to determine additional economic data that provides an improved representation of society's willingness to pay for the conservation of natural resource and the protection of intergenerational benefits.

Hypothesis 5: Per-capita GDP is only one viable indicator of the valuation, or worth, of citizens in a neoclassical marketplace. Other indicators, such as per-capita workplace productivity (output per hour of input, vice per person) were not analyzed in this study. In order to make this social discount correction factor more accurate and complete, a more robust assessment of neoclassical principles and success indices needs to be conducted to determine their convertibility to intergenerational valuation standards.

Hypotheses 4 and 5: The (combined) correction factor for Hypotheses 4 and 5, $(1 / [g_v(t) * f_v(t)])$, could arguably be applied inversely to any resultant NPV, vice directly to the modified discount rate, (effectively revaluing the NPV to account for monetary-finance substitutability and intergenerational valuation ratios). In doing so, $(1 / [g_v(t) * f_v(t)])$ would effectively be removed from the modified social discount equation (making the modified social discount rate = $[r – i']$), inverted and then reapplied to the intermediary result (NPV) of the modified social discount equation, to achieve NPV'. For simplicity and in the interest of modifying the social discount rate, vice modifying the underlying construct of the discounting equation, this study applied this function directly to the discounting rate. However, in order to both preserve the mathematical architecture of discounting (modifying the discount rate vice the discounting equation) *and* account for the neoclassical correction factors represented in $(1 / [g_v(t) * f_v(t)])$, future studies should examine the mathematical application of this correction factor to the modified social discount rate using a (1/t) exponential component to counter the exponential time-dependent adjustment this correction factor receives by virtue of being a correction to the discount rate.

# LIST OF REFERENCES

Adams, E. E. (2012, August). World forest area still on the decline. *Earth Policy Institute*. Retrieved from http://www.earth-policy.org/indicators/C56/forests_2012

Arrow, K. J., Cline, W. R., Maler, K-G., Munasinghe, M., Squitieri, R., & Stiglitz, J. E. (1996). Intertemporal equity, discounting, and economic efficiency. In J. Bruce, H. Lee, & E. Haites (Eds.), *Climate change 1995: Economic and social dimensions of climate change* (pp. 130-144). Cambridge: Cambridge University Press. Retrieved from http://www.econ.yale.edu/~nordhaus/Resources/22073-Chap4-Intertemporal%20Equity.pdf

Arrow, K., Cropper, M., Collier, C., Groom, B., Heal, G., Nordhaus, W., Pindyck, R., Pizer, W., Portney, P., Sterner, T., Tol, R. S. J., & Weitzman, M. (2013). Determining benefits and costs for future generations. *Environmental Economics, 341,* 349-350. doi:10.1126/science.1235665

Beltratti, A., Chichilnisky, G., & Heal, G. (1993, August). *Sustainable growth and the Golden Rule*. National Bureau of Economic Research (NBER) Working Paper Series. Cambridge, MA. Retrieved from http://www.nber.org/papers/w4430.pdf?new_window=1

Blackman, S. A. B., & Baumol, W. (2008). The concise encyclopedia of economics: Natural resources. *Library of Economics and Liberty*. Retrieved from http://www.econlib.org/library/Enc/NaturalResources.html

Borucke, M., Galli, A., Iha, K., Lazarus, E., Mattoon, S., Morales, J. C., Poblete, P., & Wackemagel, M. (2013, May). *The national footprint accounts, 2012 edition*. Global Footprint Network, Oakland, CA. Retrieved from http://www.footprintnetwork.org/images/article_uploads/National_Footprint_Accounts_2012_Edition_Report.pdf

Carmody, C. (2012). Considering future generations: Sustainability in theory and practice. *Australian Government: The Treasury – Economic Roundup Issue 3, 2012*. Retrieved from http://www.treasury.gov.au/PublicationsAndMedia/Publications/2012/Economic-Roundup-Issue-3/Report/Considering-future-generations-8212-sustainability-in-theory-and-practice

Costanza, R., Farber, S. C., & Maxwell, J. (1989). Valuation and management of wetland ecosystems. *Ecological Economics, 1*, 335-361. Retrieved from http://www.sciencedirect.com/science/article/pii/0921800989900141

Chutubtim, P. (2001, October). *Guidelines for conducting extended cost-benefit analysis of dam projects in Thailand*. Department of Economics, Chiang Mai University, Chiang Mai, Thailand. Retrieved from http://idl-bnc.idrc.ca/dspace/bitstream/10625/28695/1/117849.pdf

Congressional Budget Office (CBO) (1994, January). *The total costs of cleaning up nonfederal Superfund Sites.* CBO Study, Washington, D. C. Retrieved from http://www.cbo.gov/publication/15039

Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Daly, H. E., & Farley, J. (2004). *Ecological economics*. Washington, D.C.: Island Press.

Frederick, S. (2006). Valuing future life and future lives: A framework for understanding discounting. *Journal of Economic Psychology, 27*, 667-680.

doi:10.1016/j.joep.2006.05.007

Geraats, P. M. (2006, July). *Intertemporal substitution and hyperbolic discounting*. International Finance Division of the Federal Reserve Board, Cambridge, UK. Retrieved from http://www.econ.cam.ac.uk/faculty/geraats/cons_hyperb.pdf

Global Footprint Network (2012). Data and results. Retrieved from http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_data_and_results/

Harrison, M. (2010). *Valuing the future: The social discount rate in cost-benefit analysis*. Visiting Researcher Paper, Productivity Commission, Canberra, Australia. Retrieved from http://pc.gov.au/__data/assets/pdf_file/0012/96699/cost-benefit-discount.pdf

Heal, G. (2005). Intertemporal welfare economics and the environment. In K. G. Maler & J. R. Vincent (Eds.), *Handbook of Environmental Economics, Volume 3* (pp. 1105-1145). Amsterdam: North-Holland Publishing Company.

International Monetary Fund (2008, April). World economic outlook: Housing and the business cycle. *World Economic and Financial Surveys*. Retrieved from http://www.imf.org/external/pubs/ft/weo/2008/01/pdf/text.pdf

Jeuland, M. (2010). Social discounting of large dams with climate change uncertainty. *Water Alternatives, 3*(2), 185-206. Retrieved from www.water-alternatives.org

Killian, L. (2013). Oil price volatility: Origins and effects. *World Trade Organization, Research and Analysis.* Retrieved from http://www.wto.org/english/res_e/publications_e/wtr10_forum_e/wtr10_kilian_e.htm

Keohane, N. O., & Olmstead, S. M. (2007). *Markets and the environment*. Washington, D.C.: Island Press.

Keppler, J. H. (2010). *How competitive is nuclear energy?* Nuclear Energy Agency (NEA) News No. 28.1. Retrieved from http://www.oecd-nea.org/nea-news/2010/28-1/NEA-News-28-1-1-how-competitive.pdf

Krautkraemer, J. A. (2005, April). *Economics of natural resource scarcity: The state of the debate.* Resources for the Future, Discussion Paper 05-14, Washington, D.C. Retrieved from http://www.rff.org/Documents/RFF-DP-05-14.pdf

Krugman, P. (2011a, May 2). A commodity peak? *The New York Times*. Retrieved from http://krugman.blogs.nytimes.com/2011/05/02/a-commodity-peak/

Krugman, P. (2011b, May 3). Resources, inflation, and monetary policy. *The New York Times*. Retrieved from http://krugman.blogs.nytimes.com/2011/05/03/resources-inflation-and-monetary-policy/?_r=0

Marks, S. (2011, March). *Valuing the future: Intergenerational discounting, its problems, and a modest proposal*. Boston University of Law Working Papers No. 11-12, Boston, MA. Retrieved from http://www.bu.edu/law/faculty/scholarship/workingpapers/documents/MarksS031111.pdf

Mongabay (2013). Copper – free price chart: Copper (historical annual data). *Commodity Price Data.* Retrieved from http://www.mongabay.com/commodities/prices/copper.php

Newman, J. (2011, October 10). Changing the way we value the future in climate change economics. *Presidio Economics*. Retrieved from http://www.triplepundit.com/2011/10/changing-value-future-climate-change-economics/

Patzek, T. W., & Croft, G. D. (2010). A global coal production forecast with multi-Hubbert cycle analysis. *Energy*, *35*, 3109-3122. Retrieved from http://gaia.pge.utexas.edu/papers/EnergyCoalPaperPublished.pdf

Pozdena, R. (2011). Sustainability and the discount rate: An economist's perspective. *Oregon State Bar: Sustainable Future Section*. Retrieved from http://osbsustainablefuture.org/home/section-newsletter/20114winter1pozdena/

Price, C. (2006). Economics of sustainable development: Reconciling diverse intertemporal perspectives. *Welfare economics and sustainable development* (pp. 1-12). Bangor, UK: School of the Environment and Natural Resources, University of Wales, Bangor. Retrieved from http://www.eolss.net/Sample-Chapters/C13/E1-21-02.pdf

Ptacek, F., & Rippy, D. A. (2013). Owners' equivalent rent and the Consumer Price Index: 30 years and counting. *Prices & Spending, 2*(14). Retrieved from http://www.bls.gov/opub/btn/volume-2/owners/equivalent-rent-and-the-consumer-price-index-30-years-and-counting.htm

Pugel, T. A. (2012). *International economics* (15th ed.). New York: McGraw-Hill.

Rabi, A. (1996). Discounting of long-term costs: What would future generations prefer us to do? *Ecological Economics, 17*(3), 137-145. Retrieved from http://www.sciencedirect.com/science/article/pii/S0921800996800024

Randolph, J., & Masters, G. M. (2008). *Energy for sustainability*: *Technology, planning, and policy*. Washington, D.C.: Island Press.

Schelling, T. C. (1995). Intergenerational discounting. *Energy Policy, 23*(4/5), 395-401. Retrieved from http://www.uri.edu/artsci/ecn/starkey/ECN342/Schelling.pdf

Senge, P. (2009). Sustainability: Not what you think it is. *MIT Management Review,* 1-8. Retrieved from https://edge.apus.edu/access/content/group/190890/Reading%20Folder%20Week%201/Sustainability_Not_What_You_Think_It_Is.pdf

Srinivas, N. N. (2011, October 6). What drives the copper's price volatility? *The Economic Times*. Retrieved from http://economictimes.indiatimes.com/opinion/policy/what-drives-the-coppers-price-volatility/articleshow/10251233.cms

Sterner, T. (2013, August 5). From our economists: The cost of climate change 100 years from now. *Environmental Defense Fund*. Retrieved from http://www.edf.org/blog/2013/08/05/our-economists-cost-climate-change-100-years-now

Stuip, M. A. M., Baker, C. J., & Oosterberg, W. (2002). *The socio-economics of wetlands*. Wetlands International and RIZA, The Netherlands. Retrieved from http://www.wetlands.org/LinkClick.aspx?fileticket=OQzbLZJdKcU%3D&tabid=56

Sumaila, U. R., & Walters, C. (2005). Intergenerational discounting: A new intuitive approach. *Ecological Economics, 52*(2), 135-142. doi:10.1016/j.ecolecon.2003.11.012

The Daily Bell (2012, January 9). Neoclassical economics. *Glossary*. Retrieved from http://thedailybell.com/3445/Neoclassical-Economics

The World Bank Group (2013). World development indicators: GDP (current US$). *World DataBank*. Retrieved from http://databank.worldbank.org/data/views/report/tableview.aspx#

Trading Economics (2013). United States GDP. Retrieved from http://www.tradingeconomics.united-states.gdp

U.S. Bureau of Economic Analysis (BEA) (2013). Gross Domestic Product (GDP): Current dollar and "real" GDP. *National Economic Accounts.* Retrieved from http://www.bea.gov/national/index.htm

U.S. Bureau of Labor Statistics (BLS) (2008). Common misconceptions about the Consumer Price Index: Questions and answers. *Consumer Price Index*. Retrieved from http://www.bls.gov/cpi/cpiqa.htm

U.S. Bureau of Labor Statistics (BLS) (2012a). Relative importance of components in the Consumer Price Indexes: U.S. city average, December 2012. *Table 1 (2009-2010 Weights)*. Retrieved from http://www.bls.gov/cpi/cpiri2012.pdf

U.S. Bureau of Labor Statistics (BLS) (2012b). Table 1300. Age of reference person: Annual expenditure means shares, standard errors, and coefficient of variation. *Consumer Expenditure Survey, 2012*. Retrieved from http://www.bls.gov/cex/2012/combined/age.pdf

U.S. Bureau of Labor Statistics (BLS) (2013). Consumer price index: All urban consumers. *Databases & Tables – Top Picks.* Retrieved from http://data.bls.gov/cgi-bin/surveymost?cu

U.S. Census Bureau (2012). International database. *International Programs.* Retrieved from http://www.census.gov/population/international/data/idb/region.php?N=%20Results%20&T=7&A=separate&RT=0&Y=1950&R=-1&C=US

U.S. Environmental Protection Agency (EPA) (2007). Discounting benefits and costs. *TTN/Economics & Cost Analysis Support: OAQPS Economic Analysis Resources Document.* Retrieved from http://www.epa.gov/ttnecas1/econdata/Rmanual2/8.3.html

U.S. Environmental Protection Agency (EPA) (2011). Developing and documenting OSWER cost estimates. *Superfund*. Retrieved from http://www.epa.gov/superfund/policy/remedy/costest.htm

U.S. Environmental Protection Agency (EPA) (2013a). Achievements in Stratospheric Ozone Protection. *Ozone Layer Protection*. Retrieved from http://www.epa.gov/ozone/2007stratozoneprogressreport.html

U.S. Environmental Protection Agency (EPA) (2013b). Frequently asked questions on mortality risk valuation. *National Center for Environmental Economics*. Retrieved from http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html

Venuto, C. (2012). Elements of sustainable design: EVSP 561 - Week 6. Retrieved from American Public University

Weitzman, M. L. (1998). Why the far-distant future should be discounted at its lowest possible rate. *Journal of Environmental Economics and Management, 36,* 201-208. Retrieved from http://nyttekost-web.sharepoint.com/Documents/120521%2009%20weitzman%201998%20o.pdf

Whited, M., Ackerman, F., & Jackson, S. (2013, September). *Water constraints on energy production: Altering our current collision course.* Prepared for the Civil Society Institute, Cambridge, MA. Retrieved from www.civilsocietyinstitute.org

Zilberman, D. (1999). Forestry economics: EEP 101 – Lecture #13. Department of Agricultural and Resource Economics, University of California at Berkeley. Retrieved from http://are.berkeley.edu/courses/EEP101/Detail%20Notes%20PDF/Cha13,%20Forestry%20Economics.pdf

APPENDIX A – A normative examination of prescriptive social discount rates, r’, and their implications on equivalent present values (PV):

Comparing the implications of social discount rates: The lower the social discount rate, the higher the equivalent present value, and therefore the better any resource or ecological or resource conservation action will fare in a present-day cost-benefit analysis (using intertemporal discounting). This relationship is depicted in Figure A. Additionally, negative social discount rates yield present values that are *greater* than the forecasted future benefits of any present-day action. This would effectively motivate maximum conservation-based decision making for future generations, but conversely could risk depriving current generations of adequate resources for themselves. Thus, from a prescriptive perspective, a ‘balanced’ social discount rate is necessary to promote intergenerational equity.

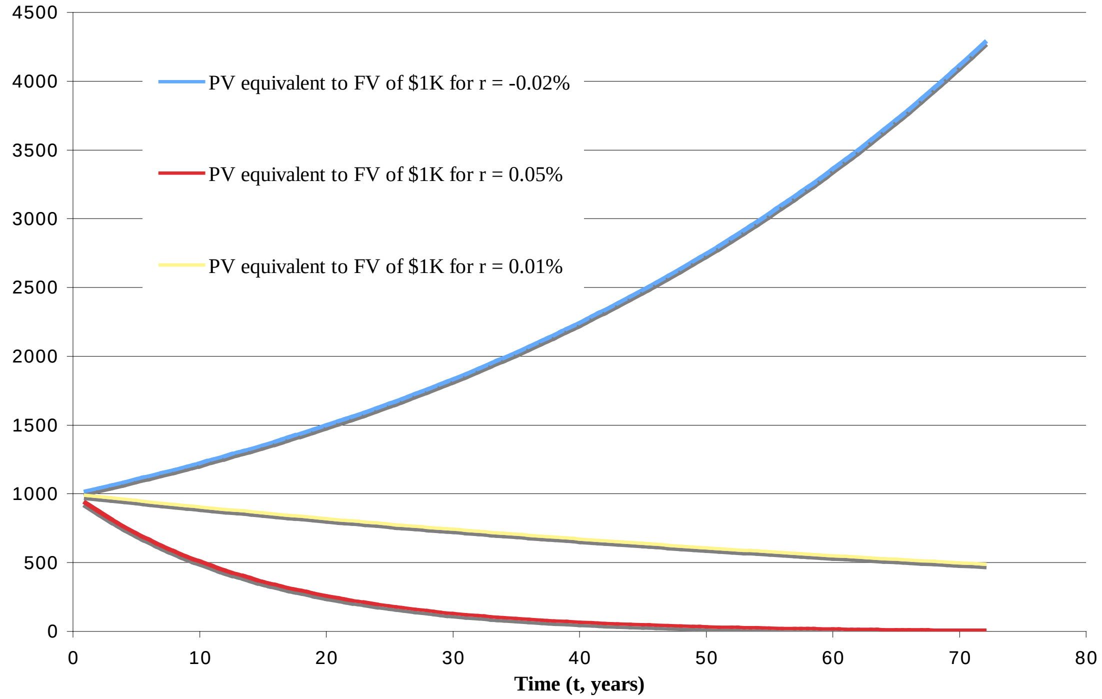

**Figure A. Present Value (PV) equivalent to a Future Value (FV) of $1K, at time (t), giver prescriptive social discount rates: r = -0.02%, 0.05%, 0.01%**

APPENDIX B – Considerations for marginal utility and inflation in social discounting:

Per Arrow et al. (2013), increased productivity yields a positive discounting value due to reduced marginal utility for "richer" generations. Though the OMB and EPA consider this factor in their social discounting calculations, it will not be accounted for in this study for three reasons:

1) Marginal utility (or 'perceived utility' due to preexisting social well-being levels) is not factored into neoclassical efficiency calculations (which are not concerned with the distribution equality of resources in their maximization of net benefits) and thus does not abide by the neoclassical, positive approach used in this study for modifying social discount rates (Pugel, 2012).

2) Per Daly & Farley (2004) "measures such as the ISEW suggest that society is already growing poorer, not richer, if we take into account external costs" (p. 274).

3) Marginal utility standards are grossly inaccurate due to the false assumptions that they are uniform across nations, years, and consumption levels (constant slope of marginal utility, or income/consumption elasticity of marginal utility) (Schelling, 1995).

The OMB and EPA *do* both account for inflation in their lower social discounting rate (the EPA's standard rate and the OMB's test rate) of 3% (referred to as the 'consumption' discount rate as it is based on a decreasing marginal utility rate as a function of increasing time-based consumption trends) (Arrow et al., 2013; Harrison, 2010; EPA, 2007). As this study contends, the 3% consumption discount rate combines factors that are aligned with only *some* of the neoclassical principles leveraged by this study (inflation and corresponding devaluation of the USD), with those that are not (consumption-based changes to marginal utility). Consequently, for the examined hypotheses and ends of this study – correcting social discount rates using descriptive methodologies while sustaining neoclassical principles – inflation should be accounted for as a correction factor to the higher 7% market-based discount rate, but in the absence of the marginal utility rate (for reasons mentioned above). Thus, in its examination of a refined social discount rate using positive methods and a neoclassical framework, this study promotes the incorporation of inflation as one of several additional correction factors to the preexisting market-based investment discount rate.

## APPENDIX C – Long run/compound inflation rates, r and r', calculated using CPI-U indices and the discount equation for: year 1963 as t = 0, (r); and year 2012 as t = 0, (r'):

r = (FV/PV)^(1/t)-1

**Compound Inflation Rates, r and r', for Energy**

| Year | Time | CPI | %I | r | r' |
|---|---|---|---|---|---|
| 1963 | 0 | 22.60 | N/A | N/A | N/A |
| 1964 | 1 | 22.50 | -0.44 | -0.44 | 4.99 |
| 1965 | 2 | 22.90 | 1.78 | 0.66 | 5.11 |
| 1966 | 3 | 23.30 | 1.75 | 1.02 | 5.18 |
| 1967 | 4 | 23.80 | 2.15 | 1.30 | 5.26 |
| 1968 | 5 | 24.20 | 1.68 | 1.38 | 5.33 |
| 1969 | 6 | 24.80 | 2.48 | 1.56 | 5.41 |
| 1970 | 7 | 25.50 | 2.82 | 1.74 | 5.48 |
| 1971 | 8 | 26.50 | 3.92 | 2.01 | 5.55 |
| 1972 | 9 | 27.20 | 2.64 | 2.08 | 5.59 |
| 1973 | 10 | 29.40 | 8.09 | 2.67 | 5.66 |
| 1974 | 11 | 38.10 | 29.59 | 4.86 | 5.60 |
| 1975 | 12 | 42.10 | 10.50 | 5.32 | 5.03 |
| 1976 | 13 | 45.10 | 7.13 | 5.46 | 4.89 |
| 1977 | 14 | 49.40 | 9.53 | 5.74 | 4.83 |
| 1978 | 15 | 52.50 | 6.28 | 5.78 | 4.69 |
| 1979 | 16 | 65.70 | 25.14 | 6.90 | 4.65 |
| 1980 | 17 | 86.00 | 30.90 | 8.18 | 4.08 |
| 1981 | 18 | 97.70 | 13.60 | 8.47 | 3.34 |
| 1982 | 19 | 99.20 | 1.54 | 8.10 | 3.02 |
| 1983 | 20 | 99.90 | 0.71 | 7.71 | 3.07 |
| 1984 | 21 | 100.90 | 1.00 | 7.38 | 3.16 |
| 1985 | 22 | 101.60 | 0.69 | 7.07 | 3.24 |
| 1986 | 23 | 88.20 | -13.19 | 6.10 | 3.33 |
| 1987 | 24 | 88.60 | 0.45 | 5.86 | 4.03 |
| 1988 | 25 | 89.30 | 0.79 | 5.65 | 4.17 |
| 1989 | 26 | 94.30 | 5.60 | 5.65 | 4.31 |
| 1990 | 27 | 102.10 | 8.27 | 5.74 | 4.26 |
| 1991 | 28 | 102.50 | 0.39 | 5.55 | 4.08 |
| 1992 | 29 | 103.00 | 0.49 | 5.37 | 4.26 |
| 1993 | 30 | 104.20 | 1.17 | 5.23 | 4.45 |
| 1994 | 31 | 104.60 | 0.38 | 5.07 | 4.63 |
| 1995 | 32 | 105.20 | 0.57 | 4.92 | 4.87 |
| 1996 | 33 | 110.10 | 4.66 | 4.92 | 5.13 |
| 1997 | 34 | 111.50 | 1.27 | 4.81 | 5.16 |
| 1998 | 35 | 102.90 | -7.71 | 4.43 | 5.42 |
| 1999 | 36 | 106.60 | 3.60 | 4.40 | 6.43 |
| 2000 | 37 | 124.60 | 16.89 | 4.72 | 6.65 |
| 2001 | 38 | 129.30 | 3.77 | 4.70 | 5.84 |
| 2002 | 39 | 121.70 | -5.88 | 4.41 | 6.02 |
| 2003 | 40 | 136.50 | 12.16 | 4.60 | 7.29 |
| 2004 | 41 | 151.40 | 10.92 | 4.75 | 6.77 |
| 2005 | 42 | 177.10 | 16.97 | 5.02 | 6.26 |
| 2006 | 43 | 196.90 | 11.18 | 5.16 | 4.81 |
| 2007 | 44 | 207.72 | 5.50 | 5.17 | 3.79 |
| 2008 | 45 | 236.67 | 13.93 | 5.36 | 3.45 |
| 2009 | 46 | 193.13 | -18.40 | 4.77 | 0.98 |
| 2010 | 47 | 211.45 | 9.49 | 4.87 | 8.41 |
| 2011 | 48 | 243.91 | 15.35 | 5.08 | 7.88 |
| 2012 | 49 | 246.08 | 0.89 | 4.99 | 0.89 |
|  |  |  | AVERAGE | **4.74** | **4.83** |

**Table C. Long run/compound inflation rates, r and r', calculated using CPI-U indices and discount equation with year 1963 as t = 0 (r) and year 2012 as t = 0 (r'): r = (FV/PV)^(1/t)-1 (Source: BLS, 2013)**

| | Energy | | Compound Inflation Rates | |
|---|---|---|---|---|
| | **CPI** | **%I** | **r, start: t=0** | **r', start: t=49** |
| **Correlation, r** | 0.938 | -0.032 | 0.405 | 0.033 |
| **p-value** | 2.96E-24 | 8.29E-01 | 3.81E-03 | 8.20E-01 |
| **$p < 0.05$; $p < 0.001$**<br>**(CPI) ; (%I)** | YES | NO | YES | NO |

**Table CC. Pearson product moment correlation test for correlation coefficient, r; and statistical significance test for $p < 0.05$, $p < 0.001$, of CPI-U and inflation (%) indices**

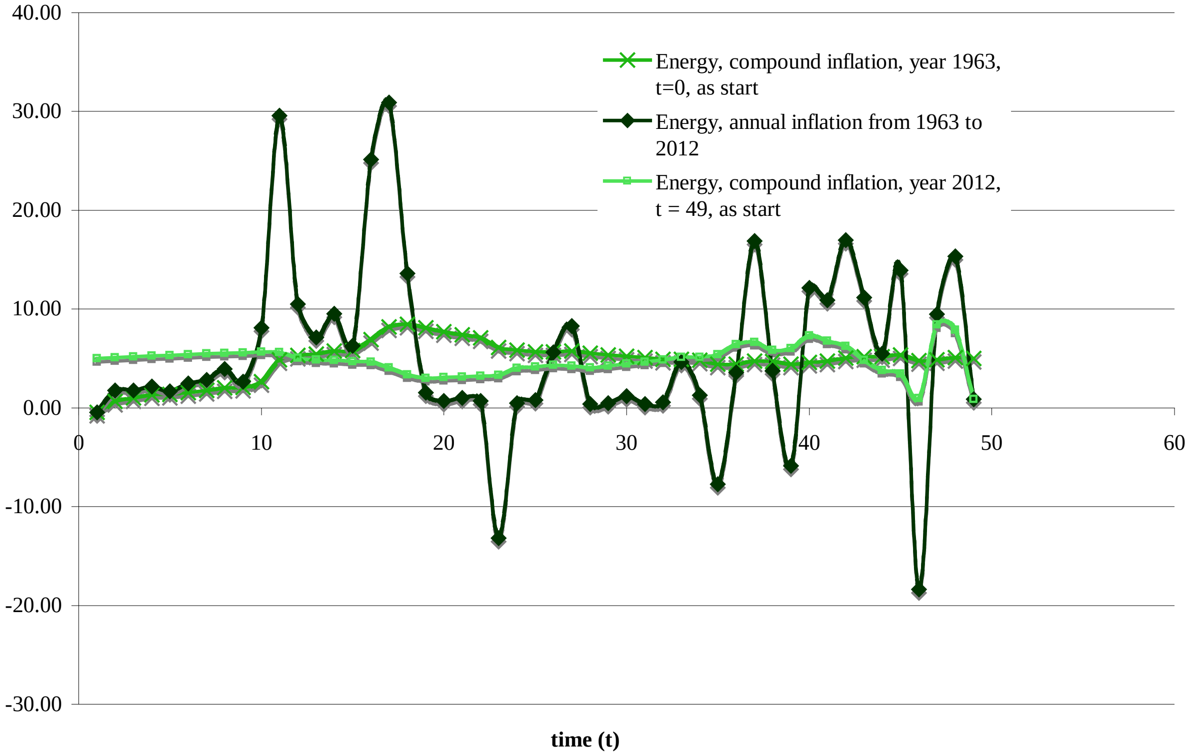

**Figure C. Comparison of year-to-year and compound energy inflation rates (%) vs. time (t)**