Choice of utility functions in integrated assessment: How subjective well-being functions can influence policy analysis

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Abstract:

To help inform public policy benefit-cost analysis, modelers calculate the change in expected utility of a society. This utility calculation often is a function of GDP per capita or economic consumption. Less widely used are subjective well-being utility functions that include relative consumption levels as well as absolute levels of consumption. This paper explores how utility function formulation can change the outcome of a benefit-cost analysis. The choice of functional form is vital to realistically projecting the utility impacts of a public policy and making the correct policy decision. Using climate change policy as an example, the study shows that a simplified subjective well-being utility function would encourage policy makers to enact mitigation policy to prevent a large decrease in society's long-term utility, while a typical GDP/capita utility calculation would encourage policymakers not to enact mitigation policy. This example highlights the practical significance of choosing an appropriate utility measure. The study concludes that the choice of utility function could change the results of cost-benefit analyses and integrated assessment models.

Keywords:
Utility functions, Subjective well-being, Climate change, Integrated assessment, Public policy analysis, Climate mitigation, System Dynamics

Introduction

To help inform public policy cost-benefit analysis, modelers calculate the change in expected utility of a society. This utility calculation often is a function of absolute GDP per capita or economic consumption. Less widely used are subjective well-being utility functions that include relative consumption levels as well as absolute levels of consumption. This paper explores how utility function formulation can change the outcome of a benefit-cost analysis.

The next section introduces the two different utility functions considered. Descriptions of both the traditional utility function and the subjective well-being provide a basis for further discussion. Following these short descriptions, the dynamic behavior of the utility functions is compared. The fundamental differences are exposed. In order to provide context for these difference, the fourth section of this paper describes public policy example: utility changes from climate change mitigation. A thorough discussion and conclusion wrap up the paper.

Differing Utility Functions

Traditional utility functions

Traditional economic analysis calculates utility as a function of the consumption of a bundle of goods. Often for public policy analysis, the function's primary parameter is simplified to a fraction of GDP per capita, which is thought of as an individual's budget of economic consumption. A society's total utility, then, is the aggregate of individual utilities.

$$\text{Traditional utility} = f(\text{Current per Capita Consumption, Population}) \tag{1}$$

The shape of traditional utility functions is based on standard economic assumptions including the following:

> (1) each individual's well-being depends only on the absolute level of that individual's consumption;
>
> (2) more consumption per capita always increases utility (happiness) – that is, more is always better.

It is important to note that these assumptions mean that optimizing agents defined with a traditional utility function will always desire more consumption, no matter what their relative level of consumption. That is, desire is never satiated. This non-satiating feature of traditional economic models drives the need for GDP growth at all costs. The single-parameter function disregards other events and quality of life issues that may also contribute positively to utility.

Subjective well-being utility

While most integrated assessment models and CBA studies use a traditional economic utility function, a relatively new measure called subjective well-being provides an alternative. Subjective well-being (SWB) is the scientific analysis of how people evaluate their lives, incorporating the results of social and psychological research (Diener et al., 2003). Adaptation, which refers to a person adjusting a new situation, is one of the fundamental principles of SWB (Diener, 2000; see also Kahneman, 2003; Tversky & Kahneman, 1974). For example, after receiving a raise, an individual initially experiences increased utility proportional to the raise. Over the course of only a few months, though, their utility returns to a base level even though they are still earning more money than before the raise. On an absolute scale, they are better than before, but they are only marginally better over their near-past time horizon. The failure of utility to rise permanently with increased consumption, as assumed by traditional utility theory, is attributed to people's habituation to their actual consumption levels, a process known as *hedonic adaptation* or the *hedonic treadmill* (Brickman & Campbell, 1971).

The following equations (Equations 2 and 3) illustrate how the hedonic treadmill may be conceived. SWB utility is a function of the ratio of the current consumption and a reference consumption. This reference consumption is itself a function of an individual's historical consumption and time constant of expectation adjustment. Continuing the salary example, the reference variable function of historical salaries and a time constant relating to how quickly an individual becomes accustom to a salary change.

$$\text{SWB Utility} = f\left(\frac{\text{Current per Capita Consumption}}{\text{Reference per Capita Consumption}}, \text{Population}\right) \qquad (2)$$

$$\text{Reference per Capita Consumption} = f\ (\text{Past Consumption, Habituation Time Constant}) \qquad (3)$$

Subjective well-being theory provides an alternative utility calculation based on an agent's relative, not absolute, levels of consumption and other parameters. In this calculation, personal consumption is only small contributor to utility, especially after basic living needs have been met. Instead, consumption levels of an individual's peer group, those they compare themselves against, can be more important in determining a person's happiness. Other factors including personal health and the number and quality of relationships can be important in determining individual utility or happiness. Ultimately a subjective well-being utility function would include all of these factors. This study, however, only utilizes a SWB utility function with relative consumption per capita. This simplifies SWB utility function and allows for easier comparison to the traditional utility. The implications of a more complete SWB utility function are considered in the discussion.

The question posed in this paper is the following: How does public policy evaluation change if a subjective-well being utility function is used instead of the more standard traditional economic theories? The next two sections of the paper try to answer this question by first examining general utility function behavior, and then using a simple public policy example.

Dynamic Behavior of the Utility Functions

In order to understand how utility functions could affect integrated assessment models or a cost-benefit analysis, this next section examines utility function behavior in response to predefined inputs. The subjective well-being utility function is dynamic, with the reference value in the denominator updating over time. This updating captures the "treadmill" response to people's expectations. On the other hand, the traditional utility function doesn't update, so isn't dynamic over time unless the inputs are changing.

To examine this behavior most closely, consider three different simple input functions. Figure 1 shows the dynamics of three different "GDP scenarios." They can be thought of as changes to individual consumption. The first scenario is a Step Decrease in consumption, such as an individual receiving a 50% pay cut. Here, consumption is decreased and remains constant for the remainder of the simulation. Another scenario is a Step Increase, in which an individual's salary is doubled and remains constant (the top line in Figure 1). The third function is a linear decrease in consumption. In this scenario, an individual is able to consume gradually less until the end of the simulation when they reach 50% of their original consumption.

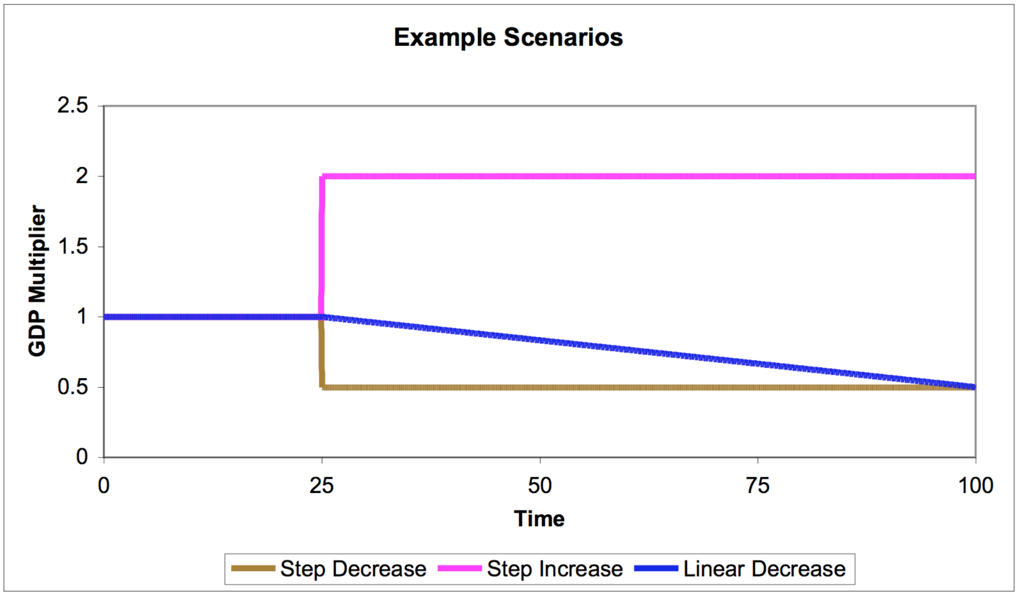

Figure 1 - Example consumption scenarios used to illustrated the behavior of the utility functions to different changes in consumption.

So how do the traditional and subjective well-being utility functions behave in response to these three different consumption scenarios? Figure 2 summarizes the results. The top-most and bottom-most flat lines are the responses of the traditional utility function to the Step Increase and Step Decrease consumption inputs. Utility decreases or increases and then remains constant for the rest of the simulation, much like the input functions. This behavior reflects that the traditional function defines utility as a function of the absolute amount of consumption. When consumption increases and decreases permanently, so does overall utility.

The subjective well-being function behaves differently to the step increase and decrease functions. For the Step Increase, the SWB function rises immediately upon the consumption increase like the traditional utility function. Instead of remaining at the elevated utility level, though, over time utility returns to the initial level (see Figure 2, the second curve from the top). The SWB utility function has a similar response to the step decrease, dropping initially and then returning to the initial level of utility. These responses highlight the adaptive nature of an individual's reference consumption. Over time, individuals become accustom to the change in their level of consumption. Initially they have an increase or decrease in happiness. Given enough time, many individuals adjust their expectations to the new level of consumption, changing their baseline for comparison, and their utility returns to the initial level.

A long-term slow decrease in consumption causes a different response for each utility function. Since traditional utility is only a function of absolute consumption, utility slowly decreases as absolute consumption decreases (see Figure 2, the third curve from the bottom toward the end of the simulation). In contrast, the SWB utility drops more significantly at the beginning and then decreases with a relatively flat slope until the end of the simulation (second curve from the bottom). The sharp initial decrease is the result of the ratio of current consumption to the reference level of consumption. Initially the ratio drops because the current consumption decreases but the reference remains relatively unchanged. Over time, the reference adapts (or updates) and the ratio comes to equilibrium. The reference level of consumption always lags the current consumption value, so the slope of the SWB utility function is always negative, but ratio is constant. The overall shape of the SWB behavior is dependent on the Habituation Time Constant of Equation 3. A longer time constant would prolong the period of steep utility decreases, delaying the time until the ratio of current consumption to reference consumption becomes constant.

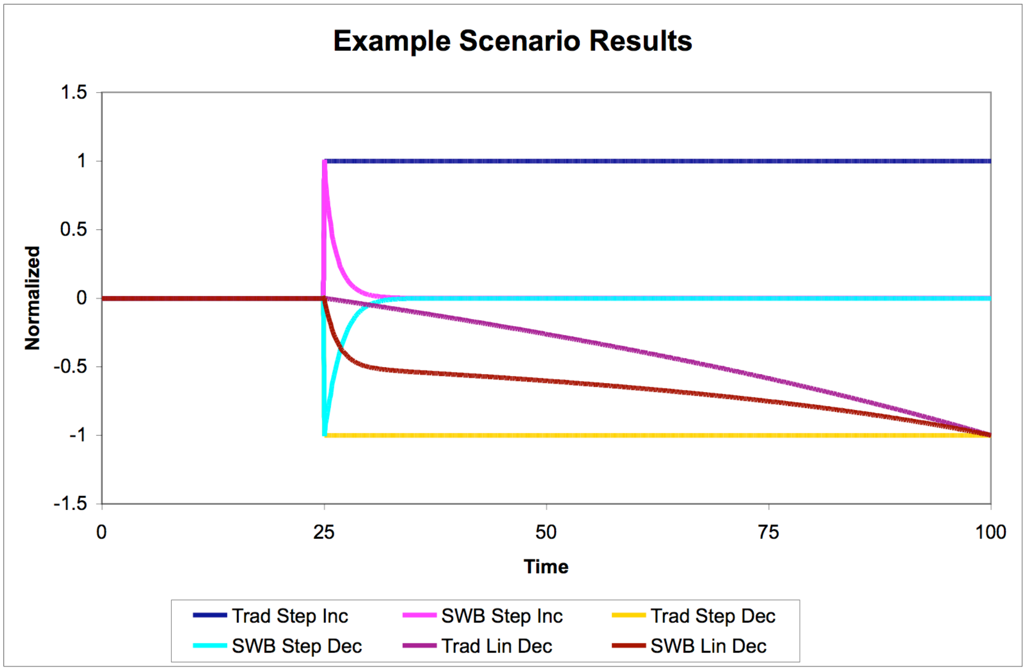

Figure 2 – Response to the traditional and SWB utility functions in response to the consumption scenarios in Figure 1. Values have been normalized between -1 and 1.

Subjective well-being utility functions have a different dynamic behavior than traditional utility functions. The three simple input consumption functions (Figure 1) demonstrate how, with simple changes in consumption, utility outcomes can be drastically different over time. What are the implications of these differences when the utility functions are embedded into an integrated assessment model? The next section uses a simple policy example to answer this question.

Public policy example: Climate change mitigation

Model Description

Many different studies cost-benefit studies have been published regarding global climate change (for example Nordhaus & Boyer, 2000; Paltsev et al., 2003). These studies largely use the traditional utility function as either the objective function of an optimization or the measure of policy impact. In this section of the paper, a simple climate change model is constructed in order to compare how replacing the traditional utility function with a subjective well-being utility function might influence the results of these types of studies.

Climate change policy has been chosen because of its environmental importance and current public interest, but other public policy issues are also subject to the choice of utility function.

The climate change model consists of three main components: 1) GDP growth, 2) policy scenarios, and 3) utility calculations. It’s economic growth path, and policy cost and damage functions have been parameterized to look at climate change policy. The time horizon of the model is 2000 to 2100. The next sections describe the model in more detail.

GDP growth and consumption

The model is driven by exogenous economic growth. The *GDP per Capita* grows exponentially at 2% per year. The model structure is a first-order exponential growth stock and flow with a *Fractional GDP Growth Rate* parameter. The variable *Consumption per Capita*, a constant fraction of *GDP per Capita* because of an assumed constant individual savings rate, is the input for both the traditional economic utility function and the SWB utility function. Comparisons of the utility functions are based on this common consumption input.

Policy cost and damage functions

Along with the economic growth, there are two other functions that are used to simply define a possible future. For given public policy area, there is a cost of policy implementation and a cost of inaction (i.e., the damage from doing nothing). These two functions are used to change the rate of the model’s economic growth.

The model’s cost and damage functions have been parameterized according to the Stern Review on the Economics of Climate Change (Stern, 2006). This report has been influential in the climate change community and provides a consistent set of parameters to base this research on. Other studies could be used in future work if desired.

The costs of climate mitigation policy are estimated by Stern to be 0.4%, 0.7% and 1% of worldwide GDP in 2015, 2025, and 2050, respectively. A table function with those data points was created, illustrated in Figure 3. From 2050 to 2100, the costs were held constant at 1% of worldwide GDP.

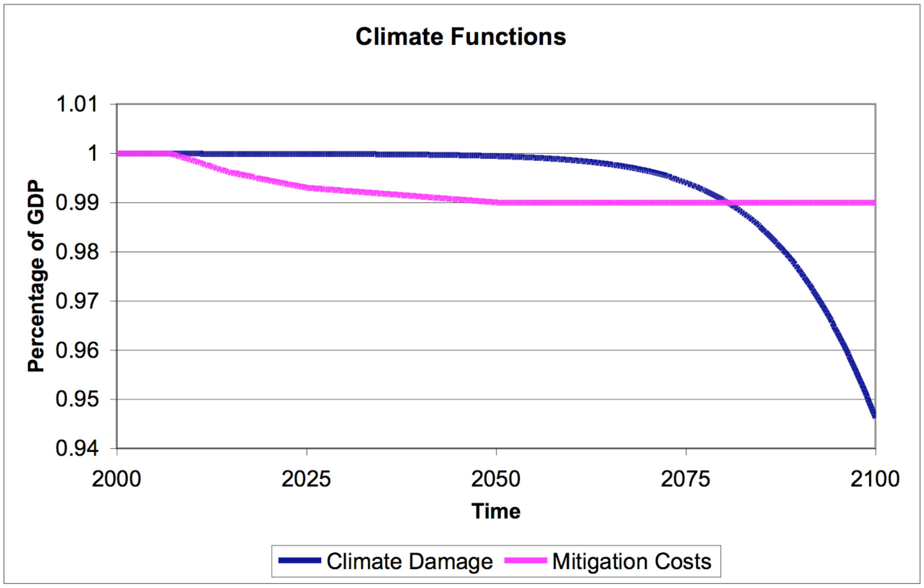

Figure 3 – The policy cost function and the climate damage function over the time horizon of hte model.

The estimates of economic damage caused by climate change vary widely in the Stern Review. The base estimate is 5% of worldwide GDP, now and forever. By including additional risks and social impacts, estimates increase to 14.4% and ~20%, respectively. For this study, I used the conservative 5% of worldwide GDP, which is most inline with other climate damage studies. The damages increase from 2000 to 2100 according to a logistic function. The maximum amount of damage is 5% occurring in 2100.

These cost and damage functions can be switched on or off depending on the desired scenario. Currently there are no feedbacks between the functions. The effects of each function separately on utility are reported below.

Calculating utility

The two utility functions are similar except for the inclusion of the *Reference Consumption per Capita* parameter in the SWB utility function. This is the individual's expected consumption from past experience. The two utility functions use the natural log of consumption (i.e., they are monotonically increasing with diminishing returns). The two functions are:

$$\text{Traditional Utility} = \text{LN(Current Consumption per Capita)} * \text{Population} \qquad (4)$$

$$\text{SWB Utility} = \text{LN}\left(\frac{\text{Current Consumption per Capita}}{\text{Reference Consumption per Capita}}\right) * \text{Population} \qquad (5)$$

Reference Consumption per Capita has a first-order smooth structure (Sterman, 2000), which is illustrated in Figure 4. The Net Change in Consumption Reference is the difference between Current Consumption per Capita and Reference Consumption per

Capita divided by the Habituation Time. The Reference Consumption per Capita is the integral of the Change in Reference Consumption per Capita, with an initial value adjusted for the model's steady state. The Habituation Time is 18 months, a value within the range of empirical SWB studies. [NEED CITE]

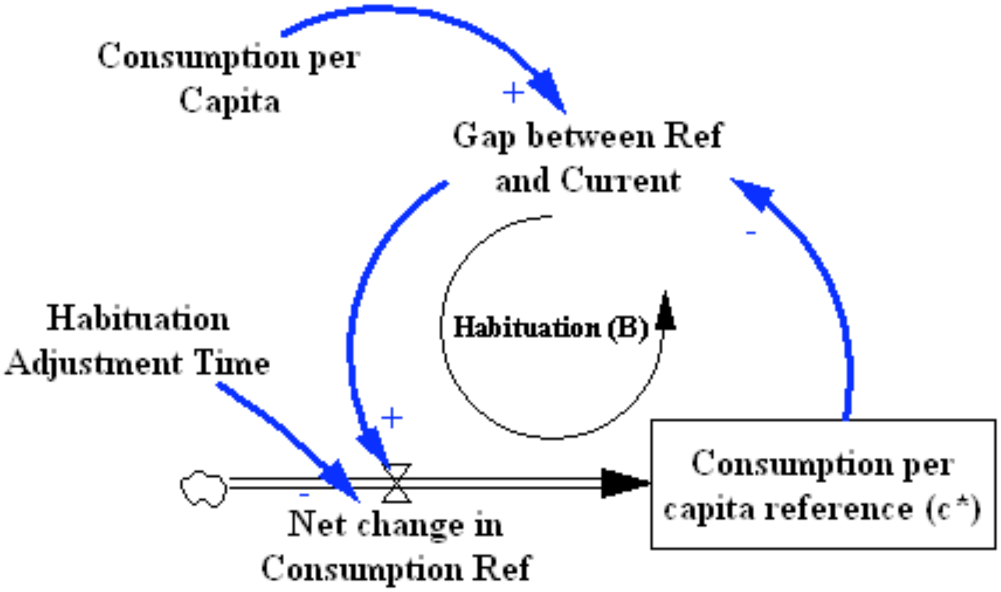

Figure 4 – The model structure of the subjective well-being habituation process.

A discount rate was used to value the stream of future utility. Again using the Stern Review as a guide, a discount rate of 0.1% was used. Currently little work has been done to test the sensitivity of the results with regard to the discount rate. The discount rate should be explored in future research because the costs and benefits of climate change are allocated over a long time horizon.

Stock structures were constructed to accumulate the flow of discounted utility for both the traditional and SWB utility functions for both the Reference and policy scenarios. The difference in cumulative discounted utility is reported in the next section.

Results

The model was used to test the change in utility for three different 'scenarios.' The first scenario is the Reference run that only includes exponential growth of 2% per year. A second scenario activated the Mitigation Cost function, along with the economic growth. This would be the change in utility if action were taken to slow the build-up of greenhouse gases. Finally, a Climate Damage scenario was run that activated the damage function (without the mitigation cost function). The results of this run represent the cost of inaction in a world in which climate change causes long-term economic harm.

The results of all three runs for both utility functions are reported in Table 1. The numbers in the table are the percentage of cumulative discounted utility loss from the Reference. The equation used is the scenario run's utility minus the reference utility, all divided by the reference utility.

	Traditional Utility	Subjective Well-being Utility
Reference	0%	0%
Mitigation Cost	-0.79%	-0.50%
Climate Damage	-0.62%	-2.35%

Table 1 – The percentage of cumulative discounted utility loss for each of the scenarios as a percentage of the Reference scenario.

For traditional utility, the cost of mitigating is similar to, and slightly less than, the amount of future climate damage. A purely benefit-cost analysis would indicate that no action should be taken, since the climate damage reduces overall utility less than the mitigation policy.

The subjective well-being utility function yields a different result. The damage from inaction is significantly larger than the decreased utility from a mitigation policy. Mitigation would be the more optimal policy choice.

The results in Table 1 show the change in utility integrated over time. Figure 5 shows the change of both utility functions to Climate Damage and Mitigation Cost scenarios. Of particular interest is the dramatic decrease in utility caused by the Climate Damage scenario using the SWB function. This behavior is similar to the linear consumption decrease of the previous section. Because of lagging adjustment to the constant degradation of consumption, the individual utility decreases dramatically compared with the traditional utility function.

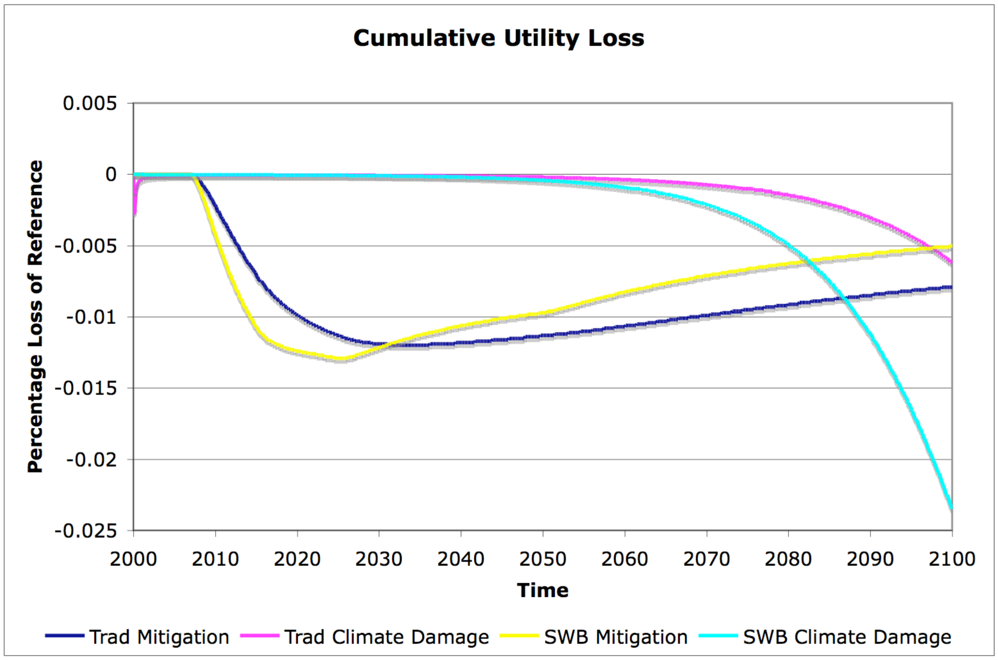

Figure 5 – The response of the traditional and SWB utility functions to the climate damage and policy cost functions.

Discussion

Utility function influences cost-benefit outcome

The use of a subjective well-being adaptive-consumption utility function instead of a traditional absolute-consumption utility function changes the benefit-cost analysis under the climate change policy scenarios presented above. In this example, the traditional function would advocate a do-nothing policy because future damages will be less costly than the mitigation policy.

Using the traditional utility function, the mitigation costs are higher because short-term GDP loss (from policy expenditures) is compounded for the entirety of the simulation. Additionally, long-term climate damages, the damages that would be avoided by the mitigation policy, are discounted diminishing their magnitude.

In contrast, the SWB utility function doesn't compound short-term loss to consumption isn't compounded over the entire century. Instead, individuals become habituated to their current level of consumption. They experience declines in utility when the growth of GDP slows because of mitigation costs. As GDP grows, their expectations of consumption are adjusting to the mitigation policy. After the short-term loss, individuals experience an increase in utility because the GDP growth rate improves over time to approximately the Reference scenario. Individuals experience a large utility loss from climate damage, however, because damages steadily increase over the simulation period. Increasing damages means a steady slowing of GDP growth, which leads to lower SWB utility because consumption expectation are constantly lagging. A benefit-cost analysis would conclude that mitigation is the better policy choice.

Not only does the SWB utility function indicate that mitigation would be cost effective, it shows that the level of damage caused by doing nothing will be higher than calculated by the traditional function. This indicates it is worth spending more to prevent future climate change damages than usually estimated in the climate change literature, which often use a traditional utility function.

Subjective well-being improvements likely to amplify differences

Ideally, subjective well-being utility functions ought to include variables such as health and quality of personal relationships. This study's SWB utility function does not include these social capital variables. Given some recent events, we can qualitatively estimate how including additional parameters in our SWB utility might change the results.

Large storm events, such as tornados, Hurricane Katrina, or river flooding, can disrupt thousands of lives. Future climate change will likely increase the frequency of these extreme weather events [CITES]. These events deteriorate personal relationships, lower employment, ruin homes, and stress emotional health. Other climate change impact studies estimate vector borne diseases to increase, causing a possible decline in human health. In short, many of these social capital variables are negatively impacted by future climate change. If there were included in the SWB utility function, the damages caused by climate change would likely increase. There would be even greater benefits to climate mitigation policies.

Conclusion

Utility functions are common in many public policy analysis models. This paper explored how a subjective well-being utility function behaves differently than the commonly used traditional utility function. The choice of the utility function type can change the outcome of an integrated assessment or a cost-benefit analysis.

The third section of this paper showed how the two different utility functions behave differently over time given three different simply consumption 'scenarios.' While the traditional utility function responded in direct correlation to the input function (i.e., the absolute level of current consumption), the subjective well-being function adjusted over time. The habituation process of the SWB function changed the overall outcomes, causing one-time consumption changes to only temporarily change utility levels. A constant degradation of current consumption also produced differences in utility, with the SWB function following a lower path over time.

The choice of functional form is vital to realistically projecting the impacts of a public policy and making the correct policy decision. Using climate change policy as an example, I illustrated that a simplified subjective well-being utility function would encourage policy makers to enact mitigation policy to prevent a large decrease in society's long-term utility.

Overall, cost-benefit analysis and integrated assessment play an important role in discussing and deciding future public policy. The choice of utility function influences the outcome of these studies. In some cases, such as climate change, the choice of utility function could even changed the sign of the cost-benefit analysis and significantly change the ratio of costs to benefits.

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