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THE WELFARE COST OF UNCERTAINTY IN POLICY OUTCOMES

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ABSTRACT

This paper proposes a simple index of the welfare significance of uncertainty in the public goods resulting as policy outcomes. Our measure is the ex ante compensation an individual would require to accept an uncertain level of service compared to receiving the expected value of the distribution of possible values for that service. Our compensation measure is a function of the coefficient of relative risk aversion, the variance in the measure of environmental service associated with policy and relevant for the individual, and a set of conventional parameters that describe the properties of nonmarket benefit measures under conditions of certainty. We would expect that the inverse virtual price elasticity of the for the environmental service and the square of the coefficient of relative variation are the primary factors influencing the size of our compensation index.

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1. Introduction

Economic analyses of policy design under uncertainty have focused primarily on situations where some limitation in regulator's knowledge is the source of the uncertainty. Most of the literature since Weitzman's [1974] classic paper considers variation in the uncertainty about costs that are assumed to be known to firms but not to policy makers. Unfortunately, in practice the policy outcomes are themselves uncertain. This uncertainty can arise for many reasons. In the case of environmental public goods, for example, policy instruments can fail to deliver the anticipated levels of compliance with the associated uncertainty in the realized emission reductions. It is also important to recognize the uncertain effects of pollutants on human health, a key motivation for these policies. There can be very different impacts for different demographic groups[1]. As a result, the welfare concepts used to evaluate such policies should be modified. To our knowledge, this distinction has not been recognized[2]. Recent research by Hafstead, Metcalf, and Williams [2016 has considered the effects of quantity uncertainty on the use of taxes versus tradeable permits. Policy analyses have continued to assume the outcomes are certain.

We propose a simple index of the welfare significance of uncertainty in the public goods resulting as policy outcomes. While our focus is on environmental regulations, the results apply to any nonmarket service resulting from a public expenditure or a regulation influencing private behavior. Our measure is the *ex ante* compensation an individual would require to accept an uncertain level of service compared to receiving the expected value of the distribution of possible values for that service. Our compensation measure is a function of the coefficient of relative risk aversion, the variance in the measure of environmental service

[1] See Currie and Schwandt [2016] for discussion of inequality in mortality rates for different demographic groups that may be at least partially due to differential exposure to air pollutants by location.

[2] Chavas and Mullarkey [2002] provide the most comprehensive effort to unify the literature on *ex ante* welfare measures under uncertainty. Using a two period model that distinguishes both the timing of decisions and the resolution of uncertainty, these authors describe how the contributions of information, risk aversion, and policy can be distinguished in *ex ante* welfare measures. Their risk measure is a conditional measure of risk aversion. It is the premium that an individual would pay *ex ante* to have knowledge of the expected values for both periods' sources of uncertainty. In this context, choices could be made under conditions that reflect compensation for resolution of the first period's uncertainty, but with only the information a risk neutral decision maker would need for private choices. Policies are defined so that they focus on changes in services that are not subject to private choice. These services can influence the choices of private consumption goods and thus would affect the decomposition of the *ex ante* compensation into the conditional value of risk and the individual's valuation for the policy. They do not consider uncertainty in the policy outcomes as we treat it here.

associated with policy and relevant for the individual, and a set of conventional parameters that describe the properties of nonmarket benefit measures under conditions of certainty.

We use a strategy introduced by Turnovsky, Shalit, and Schmitz [1980] for evaluating the welfare implications of price uncertainty. However, our case is distinctive. In a partial equilibrium context, price instability, convexity of the indirect utility function (in non-numeraire goods), together with negligible income effects, can improve individual well-being in some cases. With uncertainty in a public good, the consumption choices of private goods will depend on the realized level of this quasi-fixed public good. In this context it is important to distinguish risk aversion arising from uncertainty in the public good from risk aversion arising from income uncertainty. With non-separable preferences, the ability to adjust the consumption levels of private goods affects how they are related. Our compensation measure illustrates how this connection, together with private adaptation, influences the importance of uncertainty in a public good. In addition the assumption of nonseparable preferences allows readily measureable features of individual demand to be used to characterize individual attitudes toward uncertainty in the amount of the quasi-fixed, nonmarket good. This strategy is analogous to Chetty's [2006]use of estimates for the labor supply elasticity together with an assumed level of complementarity between consumption and leisure to bound the coefficient of relative risk aversion.

The next section outlines the derivation of our approximation, expressing the compensation measure in terms of an index that measures an individual's aversion to uncertainty in the environmental service. The remainder of this section uses weak complementarity, the Willig [1978] condition, and the properties of conventional indirect utility function to express this risk aversion measure in terms of commonly estimated demand parameters. We conclude this note by commenting on how our index might be used in policy evaluation.

2. Compensation for Policy Uncertainty

Conventional practice assumes a quasi-concave direct utility function in terms of market goods and services. We add to these arguments a measure of the services provided by a single nonmarket, environmental resource that is assumed to be quasi-fixed from the individual's perspective. Constrained maximization of utility subject to a budget constraint yields the indirect utility function in terms of prices, income, and the quasi-fixed level of the measure of the services due to the environmental resource. We consider the welfare effects of uncertainty in this non-market service while holding prices and income constant.

Let $V(q, p, m)$ designate an individual's indirect utility function, expressed in terms of a vector of prices, p, for the n private goods and services , the nonmarket service, q, and m is income. q is a random variable with a finite variance and $\bar{q}$ the population mean. $V(.)$ is assumed to be concave in q.

Our analysis begins with the definition of a compensation measure C that is the *ex ante* payment that would hold expected utility constant at the level realized with q held at the mean value and the prices of market goods and services and individual income constant as defined in equation (1).

$$(1) \qquad E\big(V(q,p,m+C)\big) = V(\bar{q},p,m)$$

Replacing the *left side* of equation (1) with a second order Taylor series expansion, treating the partial derivatives, evaluated at $\bar{q}$, as well as given values for p and m as non-stochastic variables, we have equation (2).

$$(2) \qquad V(\bar{q},p,m+C) + \frac{\partial V}{\partial q}E(q-\bar{q}) + \frac{1}{2}\frac{\partial^2 V}{\partial q^2}\, E(q-\bar{q})^2 + \frac{\partial V}{\partial m}C + \frac{1}{2}\frac{\partial^2 V}{\partial m^2}C^2 + \frac{\partial^2 V}{\partial m \partial q}\cdot C \cdot E(q-\bar{q}) \cong V(\bar{q},p,m)$$

By rearranging terms in (2) and using the fact that $E(q) = \bar{q}$ is the baseline for comparison, we can re-write the expressions as equation (3).

$$(3) \qquad \frac{V(\bar{q},p,m+C) - V(\bar{q},p,m)}{V_m} - \frac{1}{2}\pi r_q\left(\frac{\sigma_q^2}{\bar{q}}\right) + C - \frac{1}{2}r\frac{C^2}{m} \cong 0$$

where: $\sigma_q^2 = E(q-\bar{q})^2$, the variance in the measure for the nonmarket services due to the influence of the policy along with the natural and economic processes that contribute to q;

Several terms in equation (2) have been combined into indexes that have a more direct economic interpretation. The first of these is the virtual price or Marshallian marginal willingness to pay for q, π, defined in equation (4).

$$(4) \qquad \pi = \frac{V_q}{V_m}$$

The next term is the relative risk aversion coefficient for q, $r_q = \left(-\frac{qV_{qq}}{V_q}\right)$ which describes the curvature of the preference function in terms of the non-market service. The conventional relative risk aversion coefficient for risks to income is: $r = \left(-m\frac{V_{mm}}{V_m}\right)$.

We can solve for C by using a second approximation from $(m+C)$ to m. The expression for our Taylor series in this case is given in equation (5).

$$(5) \qquad V(\bar{q},p,m) \cong V(\bar{q},p,m+C) + \frac{\partial V}{\partial m}\big(m-(m+C)\big) + \frac{1}{2}\frac{\partial^2 V}{\partial m^2}\big(m-(m+C)\big)^2$$

Simplifying and solving for $V(\bar{q},p,m+C)$ we have (6).

(6) $$V(\bar{q},p,m+C) \cong V(\bar{q},p,m) + \frac{\partial V}{\partial m}C - \frac{1}{2}\frac{\partial^2 V}{\partial m^2}C^2$$

Equation (6) yields a second expression for the term $\frac{V(\bar{q},p,m+C)-V(\bar{q},p,m)}{V_m}$. Substituting for it in (3) from equation (6) we have equation (7).

(7) $$C \approx \frac{1}{4}\pi r_q \frac{\sigma_q^2}{\bar{q}}$$

There is little empirical basis for speculating directly about the magnitude of r_q. It is difficult to develop intuition about this type of risk attitude. In this context the interrelationship between features of preferences that are, in principle, observable thru behavior is especially helpful. We can see these linkages by differentiating the expression for the virtual price of q as given in equation (4) with respect to q and making some substitutions. The step yields:

(8) $$V_{qq} = \pi_q \cdot V_m + \pi \cdot V_{mq}$$

Using the properties of the income elasticity of the virtual price of q, we can re-write (8) in terms of preference features where we have the requisite empirical experience.

(9) $$\frac{m}{\pi}\frac{\partial\pi}{\partial m} = \frac{m}{\pi}\cdot\frac{V_{qm}}{V_m} - \frac{m}{\pi}\frac{V_{mm}V_q}{V_m^2}$$

Or more compactly

(10) $$\frac{m}{\pi}\cdot\frac{\partial\pi}{\partial m} = -\frac{mV_{mm}}{V_m} + \frac{mV_{mq}}{V_q}$$

Now re-writing (8) in terms of V_{mq} we can express the relative risk aversion coefficient for q, r_q in terms of the income elasticity for π, the relative risk aversion coefficient for risks to income r, and the inverse "price" elasticity for q as in equation (11).

(11) $$r_q = s \cdot (r - n) + \theta$$

Where $s =$ the share of income that would be associated with the virtual expenditures on q, at a fixed virtual price, π, $\left(s = \frac{\pi\bar{q}}{m}\right)$; $\theta = -\frac{\partial\pi}{\partial q}\cdot\frac{\bar{q}}{\pi}$; $n = \frac{\partial\pi}{\partial m}\cdot\frac{m}{\pi}$.

Weak complementarity and the Willig [1978] condition imply that n is equal to the income elasticity of the weak complement (Palmquist [2005])[3]. As a result, for those cases where q has a private good that is a weak complement, equation (11) can be re-written using this income elasticity, ε, as equation (12).

[3] For a graphical analysis explaining how weak complementarity and the Willig condition can be related to equivalent changes in the weak complement's price see Smith and Banzhaf [2007].

(12) $r_q = s(r - \varepsilon) + \theta$

with $\varepsilon = \frac{\partial x}{\partial m} \cdot \frac{m}{x}$ with x a private good that is a weak complement to q

Using equation (12) with (7) we have an expression for C compared to the virtual expenditures for q evaluated at the expected value. Common benefit transfer strategies would use estimates for π as unit values to approximate the benefits associated with changes in q. Thus, this ratio offers a simple basis for gauging the importance of uncertainty in policy outcomes.

(13) $\frac{C}{\pi\bar{q}} \approx \frac{1}{4}(s(r - \varepsilon) + \theta)\frac{\sigma_q^2}{\bar{q}^2}$

With one further substitution, we can outline how to form some intuition for most of these measures. The virtual price flexibility, θ, can be related to the income elasticity of demand for environmental services relative to a composite elasticity of substitution between these services and a Hicksian composite good for all private goods that each individual consumes[4]. While we might expect that the income elasticity of demand for environmental services is greater than unity, there is also some indirect evidence indicating for some resources it may be less than one (see Kriström and Riera [1996]). The logic underlying the expectation for values greater that one assumes that higher demands are associated with individuals with higher incomes. If we assume the income elasticity is unity, this adaptation of Chavas' logic would imply that we consider whether private goods provide adequate substitutes for the environmental service likely to be subject to policy uncertainty. If they do not have good substitutes, then we would expect the price flexibility (in absolute magnitude) to be appreciably greater than one. So estimates of 1 to 3 for θ could be reasonable. This parameter is likely the dominant factor in gauging approximate values for our index of the importance of policy uncertainty. Most policy assessments imply the virtual expenditures for environmental services would be small and are likely under 3% of virtual income[5]. Selecting a value or range of values for the coefficient of relative risk aversion is potentially more controversial. Empirical assessments have yielded a wide range of values, some as large as 4 or 5[6]. Recent work in the context of risks to wealth would support using estimates at the high end of this range when we consider aversion to income losses[7]. By contrast, Chetty's bound for r, with modest levels of complementarity between consumption and leisure, implies a value for the coefficient of relative risk aversion of 0.97 with a range of values at the bottom end of what

[4] The relationship can be derived from Chavas [1984] analysis of mixed demands (see Smith[1992] equation (2)).
[5] Virtual income is the sum of monetary income plus the virtual expenditures (i.e. virtual price of the quasi fixed service times the amount of the service with the baseline or reference allocation of resources). Carbone and Smith [2008] provide a sensitivity analysis of the effects of the assumption about this virtual share for partial and general equilibrium measures of the excess burden of taxes that would affect nonmarket environmental services.
[6] See Meyer and Meyer's [2005] summary reports adjusted estimates between 0.8 and 2.4 for wealth and 2.8 to 7 for consumption which is likely more relevant for our income measure. See their Table 2.
[7] See Cohen and Einav [2007].

the literature would imply for risks to income --from 0.30 to 2.30. The composite of this research would suggest that using the high end of Chetty's range would be conservative.

Our compensation index for the importance of uncertainty needs one more parameter –either the "price" flexibility of income (n), using equation (11) or the income elasticity of demand for a private good(ε) known to be a weak complement to the nonmarket service, using equation(12). There are estimates of both in the literature (see Phaneuf and Smith [2005] for the case of recreation). None of these estimates for either n or ε would exceed the upper limit from Chetty's range for r and certainly not for the majority of the other literature using either n or ε. Thus, we would expect that θ and the relative variance in q are the primary factors influencing the size of ($C/_{\pi\bar{q}}$).

3. Implications

Benefit cost analyses of proposed environmental policies assume the regulations being evaluated "work". That is, the new rules are expected to yield, with certainty, the improvements in the specific dimensions of environmental quality that are being assessed. There are many examples of discrepancies between the anticipated outcomes of regulatory programs and what is actually realized. This observation is hardly surprising. Indeed, analysts use these experiences to enhance our understanding of the rulemaking process. The recent Chan et. al. [2015] assessment of the so-called "Grand Experiment" associated with the SO2 emission trading program is one notable example. These authors' detailed evaluation offered several broad conclusions. The observation most relevant to our analysis focuses on the realized changes in air quality due to the program. They found that the distribution of existing regulated facilities and their incremental costs of pollution abatement had direct implications for the program's performance. Their estimates suggest that the incremental costs for controlling air emissions increases for facilities moving from the west to the east. Thus, a design for the trading program allowing equal trades of SO2 emission permits regardless of location of the facility doing the emitting, together with prevailing wind patterns, implies greater emissions and greater ambient concentrations of SO2 and other local air pollutants in the East. Since there are also higher population densities in the East, these trading rules implied increased damages and unequal incremental costs of realizing the same level of environmental quality. Until the program was implemented policy makers did not consider the full implications of trading rules along with the geographic locations of different types of electric generating units for the realized air quality in different areas. Indeed, it was the subsequent efforts to fix the problem that lead to successful legal challenges of the overall trading systems by the private firms whose emissions were regulated.

Of course, each regulatory program will be different. Realized outcomes from the new rules depend on the actual conditions of those responsible for the emissions that are hypothesized to affect each type of environmental service. They also depend on the implementation process and the natural systems that affect the dispersal of emissions. To the extent one policy leads to recognizable differences in the uncertainty likely for environmental services provided by that program, the benefit estimates should be reduced to reflect it. Our index of compensation for risk provides a simple basis for assessing the importance of these adjustments.

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