# New Generalized Measures for Understanding the Conservatism of Regulatory Defaults in Terms of Risk

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## 1. Introduction

The question of whether or not regulatory defaults[1] should be set conservatively has long been controversial [1]. The opponent views it as needlessly costly and irrational, and the proponent as a form of protection against possible omissions or underestimation of risks.

Currently, agencies differ widely in their approaches to regulatory defaults, and the implications of these differences are not well understood as yet. For example, in the EPA risk assessment guidance for the Superfund program[2], the approved defaults for a variety of quantities are described as "90th-percentile," "reasonable upper-bound," and "reasonable worst case." In the nuclear power industry, by contrast, defaults for their risk analyses have generally been set at or near the mean of the industry to determine the right priorities for the risks. It is because the adoption of conservative defaults can cause irrelevant priorities of the risk-critical components, so-called a shadow effect[3].

Then, how should regulatory defaults be set? Bier and Jang[3] insisted that understanding of the effect of defaults should precede all others because stakeholder's interests conflict in this matter. In order words, the regulators and regulated parties have systematically different goals or utility functions. Jang[4] suggested four measures, for evaluating the effect of conservatism in regulatory defaults in terms of risk, according to the postulated behaviors of regulated parties and the diversity of interests of regulators, e.g., Maximum Gross Effect(MGE), Maximum Gross Effect of Extreme (MGEE), Maximum Pure Effect(MPE) and Maximum Pure Effect of Extreme (MPEE). They will yield the results likely to be the upper bounds on the effects of conservatism that might be observed from regulatory defaults in the real world, because they assume effectively perfect gaming. In practice, however, regulated parties will frequently have some non-zero probability of performing and disclosing the results of realistic risk analyses even when they are less favorable than the default, and correspondingly, of failing to perform realistic risk analyses even when they would have been more favorable than the default.

In this paper, new measures will be suggested for evaluating the effect of conservatism implicated in the regulatory defaults. They are the measures generalized from the previous ones[4]. They can help decision makers evaluate the levels of safety likely to result from their regulatory policies.

## 2. Review of the Previous Measures

Bier and Jang[1] insisted that the effect of conservatism implicated in regulatory defaults is a topic amenable to fairly rigorous mathematical analysis, using simple but plausible models of regulated party behavior.

As a simple measure to evaluate the effect of conservatism implicated in a particular regulatory default on the estimates of risk, Jang[4] adopted the expectation of $T$ (=$Y/X$), $E[T]$, similar to Bier and Jang[3]. Here, $X$ is the (uncertain) estimate of risk (or a risk-related parameter) that would result from a risk analysis performed using realistic parameter values and assumptions. And it assume that the variability of $X$ across the population of regulated parties is described by the probability function, $f_X(x)$. With the assumption that the regulated party has perfect knowledge about its value of $X$ (*e.g.*, it has already done a realistic risk analysis and is deciding whether to disclose the results to regulators), the risk estimate disclosed to regulators by a regulated party, $Y$, is defined as minimum of both quantities, $\{X, D\}$, where $D$ is the default value chosen for the same quantity. According to the interest of regulatory body, finally, Jang[4] suggested four measures for evaluating effect of conservatism as follows. (Note that all of them are the expectation of $T = Y/X$.)

$$MGE = \int_0^1 \frac{D}{t} \cdot f_X\left(\frac{D}{t}\right) dt + F_X(D) \tag{1}$$

$$MGEE(T_{(n)}) = n \cdot \int_0^1 \frac{D}{t} \cdot \left[F_x\left(\frac{D}{t}\right)\right]^{n-1} \cdot f_X\left(\frac{D}{t}\right) dt + [F_X(D)]^n \tag{2}$$

$$MPE = E(T|T<1) = E\left(\frac{D}{X}|X>D\right) = \int_0^1 \frac{D}{t} \cdot f_X\left(\frac{D}{t}\right) dt \tag{3}$$

$$MPEE(T_{(n)}) = n \cdot \int_0^1 \frac{D}{t} \cdot \left[F_x\left(\frac{D}{t}\right)\right]^{n-1} \cdot f_X\left(\frac{D}{t}\right) dt \tag{4}$$

## 3. New Measures: GGE and GGEE

In the previous measures, the use of a rigid assumption on the regulated party behavior (i.e., perfect choice of the minimum to disclose with the perfect knowledge about the value of $X$) yields the results likely to be the upper bounds on the effects of conservatism that might be observed from regulatory defaults in the

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[1] In the paper, 'defaults' are defined as officially approved modeling assumptions and parameter values of many uncertain and/or subjective quantities to be often specified by regulators and considered acceptable for use in risk analyses as input to regulatory decisions.

real world, because they effectively assume perfect gaming. In practice, however, regulated parties will frequently have to decide whether to use realistic or default parameter values and assumptions in advance either due to the cost of performing a realistic risk analysis, or because of regulatory sanctions for failing to disclose the available risk results. In this case, a regulated party will have imperfect knowledge of the risk level that a realistic risk analysis would reveal. Thus, regulated parties will frequently have some non-zero probability of performing and disclosing the results of realistic risk analyses even when they are less favorable than the default, and correspondingly, of failing to perform realistic risk analyses even when they would have been more favorable than the default. Other factors may also contribute to non-zero disclosure probabilities for unfavorable risk estimates. For example, some companies may have a corporate policy of developing and disclosing realistic risk estimates as a way to encourage a strong safety culture among their employees, or as a way to build credibility with regulators. In addition, in some industries (such as nuclear power), companies have a substantial economic self-interest in knowing and controlling their risk levels, since these risks affect the value of the company's assets.

Considering the regulated party behaviors above, two kinds of probabilities can be simply defined as shown in the dichotomy of Table 1. In other words, $p$ is defined for disclosure probability of unfavorable risk estimates (*i.e.*, probability of disclosing the results of realistic risk analyses even when they are less favorable than the default), and $q$ for waiver probability of favorable risk estimates (*i.e.*, probability of failing to perform realistic risk analyses even when they would have been more favorable than the default). Thus, the risk estimate disclosed to regulators by a regulated party will be given by

$$Y = \|X, D\|_p \cdot I(X \rangle D) + \|D, X\|_q \cdot I(X \le D) \tag{5}$$

where $I$ is the index function, and $\|A, B\|_C$ represents the function that choose $A$ ($B$) with the probability of $c$ ($1\text{-}c$).

Table 1. Dichotomy of Regulated Party Behavior

| Disclosure / Situation | Realistic Risk Estimate ($X$) | Default ($D$) |
|---|---|---|
| $X > D$ | $p$ | $1\text{-}p$ |
| $X \le D$ | $1\text{-}q$ | $q$ |

According to the general formulation in section 2, the expectation of $T$, so-called generalized gross effect (GGE), is defined as a new measure to evaluate the effect of conservatism implicated in regulatory defaults in the estimates of risk. GGE can be obtained in closed form for an arbitrary distribution of regulated population as follows.

$$GGE = p \cdot (1 - F_X(D)) + (1-q) \cdot F_X(D) + (1-p) \cdot \int_0^1 \frac{D}{t} \cdot f_X\left(\frac{D}{t}\right) dt + q \cdot \int_1^\infty \frac{D}{t} \cdot f_X\left(\frac{D}{t}\right) dt \tag{6}$$

In addition, the variance of $T$ can also be calculated as follows.

$$Var(T) = p \cdot (1 - F_X(D)) + (1-q) \cdot F_X(D) + (1-p) \cdot D \cdot \int_0^1 f_X\left(\frac{D}{t}\right) dt + q \cdot D \cdot \int_1^\infty f_X\left(\frac{D}{t}\right) dt - [E(T)]^2 \tag{7}$$

The range of GGE is [0,∞], dissimilar to MGE and MPE, because it covers the evaluation of the degree of underestimation as well as overestimation in risks disclosed by regulated parties. In addition, the degree of underestimation or overestimation depends on the values of both $p$ and $q$. In other words, $GGE<1.0$ in equation (6) means that the risk estimate disclosed by a regulated party will be underestimated by the degree of average [1 - $GGE$] x 100% than the real risk estimate. Meanwhile, $GGE>1.0$ presents the degree of overestimation on average [$GGE$ - 1] x 100%. We can easily find that MGE is a special case of GGE such that it is obtained by setting $p = q = 0$ in equation (6).

According to the definitions of equations (5), the expectation of order statistics for extreme risk, so-called Generalized Gross Effect of Extreme (GGEE) can be delivered as follows.

$$GPEE(T_{(n)}) = n \cdot (1-p) \cdot D \int_p^1 \frac{t}{(t-p)^2} \cdot \left[F_X\left(\frac{1-p}{t-p} \cdot D\right)\right]^{n-1} \cdot f_X\left(\frac{1-p}{t-p} \cdot D\right) dt + n \cdot q \cdot D \int_1^\infty \frac{t}{\{t-(1-q)\}^2} \cdot \left[F_X\left(\frac{q}{t-(1-q)} \cdot D\right)\right]^{n-1} \cdot f_X\left(\frac{q}{t-(1-q)} \cdot D\right) dt \tag{8}$$

Without a loss of generality, GGEE of $T_{(i)}$ from equation (8) is as follows.

$$GPEE(T_{(i)}) = (1-p) \cdot D \int_p^1 \frac{t}{(t-p)^2} \cdot f_{X_{(i)}}\left(\frac{1-p}{t-p} \cdot D\right) dt + q \cdot D \int_1^\infty \frac{t}{\{t-(1-q)\}^2} \cdot f_{X_{(i)}}\left(\frac{q}{t-(1-q)} \cdot D\right) dt \tag{9}$$

## 3. Conclusions

The desirability of conservatism in regulatory risk analyses has long been controversial. It is seen by some as needlessly costly and irrational, and by others as a form of a protection against possible omissions or underestimation of risks.

In this paper, new measures were suggested for evaluating the effect of conservatism implicated in the regulatory defaults. They are the measures generalized from the previous ones. Understanding of the conservatism implicated in regulatory defaults in terms of a risk can help decision makers evaluate the levels of a safety likely to result from their regulatory policies.

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