

The Single Parameter Pareto Revisited

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Abstract

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1 Introduction

In one of his seminal works, Stephen W. Philbrick[1] proposed an elegant solution to the complex problem of modeling claims amounts in excess layers. That solution involved the use a Pareto Type I distribution for claims above an excess threshold.

This paper expands on that work in several ways through the following:

1. A consistent notational framework
2. A review of the various formulæ including supporting derivation in the Appendices
3. Parameter values less than or equal to 1
4. Consideration of maximum probable loss using order statistics
5. Quantification of parameter uncertainty using Bayesian Markov chain Monte Carlo (MCMC) methods (expanding on the work of Meyers and Reichle & Yonkunis)
6. Frequency and severity trends
7. Dealing with claims less than the threshold (expanding on the work of Fackler)
8. Provides an errata to address certain issues in Philbrick

2 The *Single Parameter* Pareto

Philbrick’s Single Parameter Pareto (SPP) is a special case of the Pareto Type I distribution which has the following cumulative distribution function:

$$F(x) = 1 - \left(\frac{k}{x}\right)^a \quad (1)$$

Many reviewers are often confused by the reference to the *single parameter*. After all, *Philbrick*, in Section III initially presents the Pareto with two parameters (Equation 1), k and a , and then later adds that claims should be “normalized” by dividing by the “selected lower bound”

This presentation leaves many readers not understanding how the lower bound, k , lost its parameter status. Philbrick explains that this is because:

Although there may be situations where this value must be estimated, in virtually all insurance applications this value will be selected in advance. (Section III)

This explanation often leaves readers less than satisfied.

We offer the alternative that users of the SPP model should consider the process of normalizing the claims to be a transformation of the data rather than the application of a parameter. An analogous transformation occurs when we take logs. When we do that, we do not consider the base of the logarithm to be a parameter. Similarly, we will not consider the lower bound to be a parameter.

To improve clarity of this concept, we present the following:

Random Variable	Observed Claim Amount	Normalized Claims Amount
Symbol	\mathbf{Y}	\mathbf{X}
Transformation		$\mathbf{X} = g(\mathbf{Y})$ $g(\mathbf{Y}) = \mathbf{Y}/\text{lower bound}$
Domain	[lower bound, ∞]	[1, ∞]
Density	$a \frac{k^a}{y^{a+1}}$	$qx^{-(q+1)}$
Parameters	$k > 0$ (scale); $a > 0$ (shape)	$q > 0$ (shape)

Table 1: The Pareto Type I and the SPP

We can now work with model forms in the space of \mathbf{X} and then use g^{-1} to transform back into the space of \mathbf{Y} . We can also now present the density and distribution functions.

$$f(x) = qx^{-(q+1)} \quad (2)$$

$$F(x) = 1 - x^{-q} \quad (3)$$

In Appendix B.1, we provide the derivation of the distribution function (Equation (3)).

2.1 Other Pareto Forms

In Appendix A, we provide an inventory of Pareto distributions including the SPP presented in Equations (2) and (3).

3 Actuarial Formulæ

In general, we leave formula derivation to the Appendices of this paper. In Appendix B.2, we present the derivation of the expected value:

$$\mathbb{E}[X] = \begin{cases} \frac{q}{q-1}, & \text{if } q > 1 \\ \text{undefined}, & \text{if } q \leq 1 \end{cases} \quad (4)$$

We can use Equation (9), to calculate the limited expected value through b as presented in Appendix B.3 as:¹

$$\mathbb{E}[X; b] = \frac{q - b^{1-q}}{q - 1} \quad (5)$$

In that derivation, there is no restriction that $q > 1$. That is, we recognize that, although the limited expected value is undefined, expected values are defined when we have an upper limit (such as a policy limit). As such, users of the SPP need not “fear” q values less than 1 for most insurance applications.

So for the expected claim amount for the layer between a and b , we have:

$$\mathbb{E}[X; a, b] = \frac{q - b^{1-q}}{q - 1} - \frac{q - a^{1-q}}{q - 1} \quad (6)$$

$$= \frac{a^{1-q} - b^{1-q}}{q - 1} \quad (7)$$

¹Philbrick used b to refer to both the “lower bound” and the policy limit. We will not do that in this paper primarily for clarity as using a variable to represent the lower bound implied at least the possibility that the lower bound was a parameter. Conveniently, it also allows us to use the traditional policy notation as attaching at a through limit b with the resulting layer width equal to $b - a$.

4 The Parameter

5 Trend

Appendices

A An Inventory of Pareto Distributions

Appendix first content.

B Derivation of Formulæ

B.1 SPP Cumulative Distribution Function

$$\begin{aligned} F(x) &= \int_1^x f(x) \, dx \\ &= \int_1^x qx^{-(q+1)} \, dx \\ &= q \int_1^x x^{-(q+1)} \, dx \\ &= q \frac{1}{-(q+1)+1} x^{-q} \Big|_1^x \\ &= q \frac{1}{-q} x^{-q} \Big|_1^x \\ &= -x^{-q} \Big|_1^x \\ &= -x^{-q} - (-1^{-q}) \\ F(x) &= 1 - x^{-q} \end{aligned} \tag{8}$$

B.2 SPP Expected Value

We can derive the expected values as:

$$\begin{aligned}
\mathbb{E}[X] &= \int_1^\infty x f(x) \, dx \\
&= \int_1^\infty x q x^{-(q+1)} \, dx \\
&= q \int_1^\infty x^{-q} \, dx \\
&= q \frac{1}{-q+1} x^{-q+1} \Big|_1^\infty \\
&= \frac{q}{1-q} x^{-q+1} \Big|_1^\infty \\
\mathbb{E}[X] &= \frac{q}{1-q} \frac{1}{x^{q-1}} \Big|_1^\infty
\end{aligned} \tag{9}$$

We can see that for $x = 1$ (the lower limit of integration) equation (9) evaluates to $\frac{q}{1-q}$. However for $x = \infty$, we have the following²:

$$\frac{q}{1-q} \frac{1}{x^{q-1}} = \begin{cases} 0, & \text{if } q > 1 \\ \text{undefined}, & \text{if } q = 1 \\ \infty, & \text{if } q < 1 \end{cases}$$

and therefore we have:

$$\mathbb{E}[X] = \begin{cases} 0 - \frac{q}{1-q}, & \text{if } q > 1 \\ \text{undefined}, & \text{if } q = 1 \\ \infty, & \text{if } q < 1 \end{cases}$$

or more simply:

$$\mathbb{E}[X] = \begin{cases} \frac{q}{q-1}, & \text{if } q > 1 \\ \text{undefined}, & \text{if } q \leq 1 \end{cases} \tag{10}$$

²In the limit as $x \rightarrow \infty$, the expression evaluates to $-\frac{q}{q+1}$. However evaluated at ∞ , the expression is undefined.

B.3 SPP Limited Expected Value

The limited expected value is calculated as:

$$\begin{aligned}\mathbb{E}[X; b] &= \frac{q}{1-q} \frac{1}{x^{q-1}} \Big|_1^b + b(1 - F(b)) \\ &= \frac{q}{1-q} \left[\frac{1}{b^{q-1}} - \frac{1}{1^{q-1}} \right] + b [1 - (1 - b^{-q})] \\ &= \frac{q}{1-q} \left[\frac{1}{b^{q-1}} - 1 \right] + b [b^{-q}] \\ &= \frac{q}{q-1} \left[1 - \frac{1}{b^{q-1}} \right] + b^{1-q} \\ &= \frac{q}{q-1} [1 - b^{1-q}] + b^{1-q} \\ &= \frac{1}{q-1} [q - qb^{1-q} + (q-1)b^{1-q}] \\ &= \frac{1}{q-1} [q - b^{1-q}] \\ &= \frac{q - b^{1-q}}{q-1}\end{aligned}\tag{11}$$

References

- [1] Stephen W. Philbrick. A Practical Guide to Single Parameter Pareto Distribution. *Proceedings of the Casualty Actuarial Society*, LXXII:44–84, 1985.