Further Developments on the (EG) Exponential-MIR Class of Distributions

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Abstract


Keywords: T-X (W) family of distributions; Exponentiated Generalized distributions; Modified Inverse Rayleigh distribution; biological data; health data

Introduction

T-X (W) Family of Distributions
This family of distributions is a generalization of the beta-generated family of distributions first proposed by Eugene et.al [Eugene, N, Lee, C, Famoye, F: The beta-normal distribution and its applications. Communications in Statistics-Theory and Methods 31(4), 497–512 (2002)]. In particular, let \(r(t)\) be the PDF of the random variable \(T \in [a, b], -\infty \leq a < b \leq \infty, \) and let \(W(F(x))\) be a monotonically and absolutely continuous function of the CDF \(F(x)\) of any random variable \(X\). The CDF of a new family of distributions defined by Alzaatreh et.al [Alzaatreh, A, Lee, C, Famoye, F: A new method for generating families of continuous distributions. Metron 71(1), 63–79 (2013b)] is given by

\[
G(x) = \int_0^{W(F(x))} r(t)dt = R(W(F(x)))
\]

Where \(R(\cdot)\) is the CDF of the random variable \(T\) and \(a \geq 0\)

Remark 1.1
The PDF of the TX (W) family of distributions is obtained by differentiating the CDF above.

Remark 1.2
When we set \(W(F(x)) := -\ln(1-F(x))\) then we use the term “T-X Family of Distributions” to describe all sub-classes of the T-X (W) family of distributions induced by the weight function \(W(x) := -\ln(1-x)\). A description of different weight functions that are appropriate given the support of the random variable \(T\) is discussed in [Alzaatreh, A, Lee, C, Famoye, F: A new method for generating families of continuous distributions. Metron 71(1), 63–79 (2013b)] A plethora of results studying properties and application of the T-X(W) family of distributions have appeared in the literature, and the research papers, assuming open access, can be easily obtained on the web via common search engines, like Google, etc.

The Exponentiated Generalized (EG) T-X family of distributions
This class of distributions appeared in [Suleman Nasiru, Peter N. Mwita and Oscar Ngesa, Exponentiated Generalized Transformed-Transformer Family of Distributions, Journal of Statistical and Econometric Methods, vol.6, no.4, 2017, 1-17] In particular the CDF Admits the following integral representation

\[
G(x) = \int_0^{\log(1-(1-F(x))^c)} r(t)dt
\]

Where \(c, d > 0\) and \(F(x) := 1-F(x)\) and \(F(x)\) is the CDF of a base distribution.

Remark 1.3
Note that if we set \(L(x) := (1-F(x))^c\) where \(c, d > 0\) and \(L(x) := 1-F(x)\) and \(F(x)\) is the CDF of a base distribution, then \(L(x)\) gives the CDF of the exponentiated generalized class of distributions [G.M. Cordeiro, E.M.M. Ortega and C.C.D. da Cunha, The exponentiated generalized class of distributions, Journal of Data Science,11(1), (2013),1-27]
The (EG) Exponential-MIR family of distributions

Here we assume the random variable \( X \) follows the MIR distribution with CDF
\[
F_{\alpha,\theta}(x) = 1 - e^{-\frac{x^\theta}{\alpha}}
\]
And the random variable \( T \) follows the exponential distribution with PDF
\[
r_{\lambda}(t) = \lambda e^{-\lambda t}
\]
and CDF
\[
R_{\lambda}(t) = 1 - e^{-\lambda t}
\]
Now put
\[
L_{(\alpha,\theta,d,c)}(x) := (1 - F_{(\alpha,\theta)}(x))^d
c
\]
\[
G_{(\alpha,\theta,d,c)}(x) = 1 - (1 - L_{(\alpha,\theta,d,c)}(x))^c
\]

Further Developments

In this section we present some new generalizations of the (EG) Exponential-MIR family of distributions which are induced by the other weight functions introduced in [Alzaatreh, A, Lee, C, Famoye, F: A new method for generating families of continuous distributions. Metron 71(1), 63–79 (2013b)], when the random variable \( T \) in the \( T\times(W) \) class of distributions has support \([a, \infty)\], where \( a_0 \geq a \geq 0 \)

**Definition 2.1**

A random variable \( Y_1 \) will be called \( T - X \) distributed of type I if the weight function is given by
\[
W(x) = -\log(1 - x)
\]

**Definition 2.2**

A random variable \( Y_2 \) will be called \( T - X \) distributed of type II if the weight function is given by
\[
W(x) = \frac{x}{1-x}
\]

**Definition 2.3**

A random variable \( Y_3 \) will be called \( T - X \) distributed of type III if the weight function is given by
\[
W(x) = -\log(1 - x^\alpha)
\]
For some \( \alpha > 0 \)

**Definition 2.4**

A random variable \( Y_4 \) will be called \( T - X \) distributed of type IV if the weight function is given by
\[
W(x) = \frac{x^\alpha}{1-x^\alpha}
\]
For some \( \alpha > 0 \)

**Type II**

**Definition 2.5**

The CDF of the (EG) Exponential-MIR class of distributions of type II has the following integral representation for \( a \geq 0 \)
\[
K_{(\alpha,\theta,d,c)}(x) = R_{\lambda}(\frac{F_{(\alpha,\theta)}(x)}{1 - F_{(\alpha,\theta)}(x)})
\]
Where
\[
R_{\lambda}(\cdot) = 1 - e^{-\lambda(\cdot)}
\]
and
\[
F_{(\alpha,\theta)}(x) = e^{-\frac{x^\theta}{\alpha}}
\]
Note that
\[
L_{(\alpha,\theta,d,c)}(x)
\]
implies the following from Definition 2.5

**Corollary 2.6**

The CDF of the exponentiated Exponential-MIR class of distributions of type II is given by
\[
K^{*}_{(\alpha,\theta,d,c)}(x) = R_{\lambda}(\frac{F_{(\alpha,\theta)}(x)}{1 - F_{(\alpha,\theta)}(x)})
\]
Where
\[
R_{\lambda}(\cdot) = 1 - e^{-\lambda(\cdot)}
\]
and
\[
F_{(\alpha,\theta)}(x) = e^{-\frac{x^\theta}{\alpha}}
\]
Note that
\[
L_{(\alpha,\theta,d,c)}(x)
\]
implies the following from Definition 2.5

**Corollary 2.7**

The CDF of the Exponential-MIR class of distributions of type II
\[
K^{**}_{(\alpha,\theta,d,c)}(x) = R_{\lambda}(\frac{F_{(\alpha,\theta)}(x)}{1 - F_{(\alpha,\theta)}(x)})
\]
Where
\[
R_{\lambda}(\cdot) = 1 - e^{-\lambda(\cdot)}
\]
and
\[
F_{(\alpha,\theta)}(x) = e^{-\frac{x^\theta}{\alpha}}
\]

**Type III**

**Definition 2.8**

The CDF of the (EG) Exponential-MIR class of distributions of type III has the following integral representation for \( a \geq 0 \) and \( \xi > 0 \)
\[
Z_{(\alpha,\theta,d,c)}(x) = \int_{a}^{\log(1 - L_{(\alpha,\theta,d,c)}(x))^c} r_{\lambda}(t) dt
\]
Note that \( L_{(\alpha,\beta,1,1)}(x) \) implies the following from Definition 2.8

**Corollary 2.9**

The CDF of the exponentiated Exponential-MIR class of distributions of type III is given by

\[
Z'_{(\alpha,\beta,\theta,\xi)}(x) = R_{\lambda}(-\log(1 - F_{(\alpha,\beta)}(x)^{\xi})(x))
\]

Where \( R_{\lambda}(.):= 1 - e^{-\lambda(.)} \)

and \( F_{(\alpha,\beta)}(x) = e^{-\frac{\alpha}{x} \frac{\theta}{x}} \)

Note that \( L_{(\alpha,\beta,1,1)}(x) \) implies the following from Definition 2.8

**Corollary 2.10**

The CDF of the Exponential-MIR class of distributions of type III is given by

\[
Z'_{(\alpha,\beta,\theta,\xi)}(x) = R_{\lambda}(-\log(1 - F_{(\alpha,\beta)}(x)^{\xi})(x))
\]

Where \( R_{\lambda}(.):= 1 - e^{-\lambda(.)} \)

and \( F_{(\alpha,\beta)}(x) = e^{-\frac{\alpha}{x} \frac{\theta}{x}} \)

Type IV

**Definition 2.11**

The CDF of the (EG) Exponential-MIR class of distributions of type IV has the following integral representation for \( \xi > 0 \) and \( a \geq 0 \)

\[
Q_{(\alpha,\beta,\delta,\xi)}(x) = \int_{\delta}^{\xi} F_{(\alpha,\beta)}(t) R_{\lambda}(t) dt
\]

Note that \( L_{(\alpha,\beta,1,1,\delta)}(x) \) implies the following from Definition 2.11

**Corollary 2.12**

The CDF of the exponentiated Exponential-MIR class of distributions of type IV is given by

\[
Q'_{(\alpha,\beta,\delta,\xi)}(x) = R_{\lambda}(-\log(1 - F_{(\alpha,\beta)}(x)^{\xi})(x))
\]

Where \( R_{\lambda}(.):= 1 - e^{-\lambda(.)} \)

and \( F_{(\alpha,\beta)}(x) = e^{-\frac{\alpha}{x} \frac{\theta}{x}} \)

Note that \( L_{(\alpha,\beta,1,1,\delta)}(x) \) implies the following from Definition 2.11

**Corollary 2.13**

The CDF of the Exponential-MIR class of distributions of type IV is given by

\[
Q'_{(\alpha,\beta,\delta,\xi)}(x) = R_{\lambda}(-\log(1 - F_{(\alpha,\beta)}(x)^{\xi})(x))
\]

Where \( R_{\lambda}(.):= 1 - e^{-\lambda(.)} \)

and \( F_{(\alpha,\beta)}(x) = e^{-\frac{\alpha}{x} \frac{\theta}{x}} \)

Application

In this section we compare the Exponential-Weibull class of distributions of type II and the Exponential-Weibull class of distributions of type IV in modeling the aircraft data, Table 1 [Suleman Nasiru, Peter N. Mwita and Oscar Ngesa, Discussion on Generalized Modified Inverse Rayleigh, Appl. Math. Inf. Sci. 12, No. 1, 113-124 (2018)]

**Remark 3.1**

When a random variable \( X \) follows the Exponential-Weibull class of distributions of type II we write \( X \sim \text{EWII}(a, b, c) \)

**Remark 3.2**

When a random variable \( X \) follows the Exponential-Weibull class of distributions of type IV we write \( X \sim \text{EWIV}(a, b, c, d) \)

In this section we assume the CDF of the Weibull distribution is given by

\[
F_{(b,c)}(x) = 1 - e^{-\frac{x}{c}}
\]

and the CDF of the Exponential distribution is given by

\[
F_{(\alpha,\beta)}(x) = 1 - e^{-\frac{x}{\alpha}}
\]

**Theorem 3.3**

The CDF of the Exponential-Weibull class of distributions of type II is given by

\[
K_{(a,b,c)}(x) = 1 - e^{-\frac{ax}{c}}
\]

Proof in Corollary 2.7, let \( \lambda \equiv a \) and \( F_{(\alpha,\beta)}(x) \equiv F_{(b,c)}(x) \)

**Theorem 3.4**

The CDF of the Exponential-Weibull class of distributions of type IV is given by

\[
K_{(a,b,c,d)}(x) = 1 - e^{-\frac{ax}{c} \frac{(1-e^{-\frac{x}{c}})^{b}}{1-(1-e^{-\frac{x}{c}})^{d}}}
\]
Proof In Corollary 2.13, let $\xi := d$, $\lambda := a$ and $F_{\alpha,0}\beta(x) = F_{\alpha,0}\beta(x)$ In order to compare the two distribution models, we used the following criteria: -2(Log likelihood) and AIC (Akaike information criterion), AICC (corrected Akaike information criterion), and BIC (Bayesian information criterion) for the data set. The better distribution corresponds to the smaller -2(Log-likelihood) AIC, AICC, and BIC values:

$$AIC = 2k - 2l$$
$$AICC = AIC + \frac{2(k + 1)}{n - k - 1}$$
$$BIC = k \log(n) - 2l$$

Where $k$ is the number of parameters in the statistical model, $n$ is the sample size, and $l$ is the maximized value of the log-likelihood function under the considered model. From Table 1 above, it is clear the $EWII(3975.82, 1.0863, 121474)$ distribution has the smallest AICC and BIC values, whilst the $EWIV(216660, 1.47149, 1.21237\times10^7, 0.681738)$ distribution has the smallest -2(Log-likelihood) and AIC values. When we compared the CDF’s of the two distributions we obtained the following:

On the other hand when we compared the PDF’s of the two distributions we obtained the following:

The results from Table 1 and the Figures above, suggest the $EWIV(216660, 1.47149, 1.21237\times10^7, 0.681738)$ distribution is slightly better than the $EWII(3975.82, 1.0863, 121474)$ distribution in modeling the aircraft data, Table 3 [Suleman Nasiru, Peter N. Mwita and Oscar Ngesa, Discussion on Generalized Modified Inverse Rayleigh, Appl.Math. Inf. Sci. 12, No. 1, 113-124 (2018)]

Concluding Remarks

Our hope is that the researchers will further develop the properties and applications of the new class of distributions presented in this paper. Finally we hope the new developments have practical significance in modeling biological data, health data, etc.

Note that $L_{(\alpha,\beta,\lambda,c)}(X)$ implies the following from Section 1.3

<table>
<thead>
<tr>
<th>Table 1: Criteria for Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>$EWII(3975.82, 1.0863, 121474)$</td>
</tr>
<tr>
<td>$EWIV(216660, 1.47149, 1.21237\times10^7, 0.681738)$</td>
</tr>
</tbody>
</table>
Theorem 4.1

The CDF of the exponentiated Exponential-MIR class of distributions of type I is given by

\[ G_{(\alpha, \theta, d)}(x) = 1 - (1 - F_{(\alpha, \theta)}(x))^d \]

Where

\[ F_{(\alpha, \theta)}(x) = e^{-\left(\frac{x}{\lambda}\right)^\alpha} \]

Similarly, \( L_{(\alpha, \theta, l)}(x) \) implies the Exponential-MIR class of distributions of type I from Section 1.3. Consequently, several corollaries can be deduced from Chapter 5[4], where they obtained several statistical/mathematical properties with application. For example, we have the following from Section 5.2 of Chapter 5[4]

Corollary 4.2

The survival function of the exponentiated Exponential-MIR class of distributions of type I is given by

\[ S^*(x) = (1 - F_{(\alpha, \theta)}(x))^d \]

Proof Let \( d = 1 \) in eqn (5.8) contained in Section 5.2 of Chapter 5[4]

References