Package ‘learningCurve’

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Type Package

Title An Implementation of Crawford's and Wright's Learning Curve Production Functions

Version 1.1.2

Description Implements common learning curve production functions. It incorporates Crawford's and Wright's learning curve functions to compute unit and cumulative block estimates for time (or cost) of units along with an aggregate learning curve. It also provides delta and error functions and some basic learning curve plotting functions along with functions to compute aggregated learning curves, error rates, and to visualize learning curves.

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BugReports https://github.com/AFIT-R/learningCurve/issues

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**Description**

Computes the approximate aggregate cumulative learning curve formula by calculating the sum of all contributing hours from all departments for all production units 1 through n.

**Usage**

```r
agg_curve(t, r, n, na.rm = FALSE)
```

**Arguments**

- `t` vector of hours (or costs) for the first unit from departments 1 through m
- `r` vector of historical learning rates for departments 1 through m
- `n` total units to be produced across all departments
- `na.rm` Should NA values be removed?
ca_block

Examples

```r
## Not run:
# A project is expected to get underway soon to produce 300
# widgets. Three departments will be involved. Historically,
# these departments have had learning curves of 85%, 87%, and
# 80% respectively. The first unit hours for these departments
# have been estimated at 70, 45, and 25 respectively. What is
# the total predicted hours required for the entire effort?

t <- c(70, 45, 25)
```r

```r
r <- c(.85, .87, .8)

agg_curve(t = t, r = r, n = 300)
## [1] 11000.96

## End(Not run)
```

---

**ca_block**

*Wright’s Cumulative Average Learning Curve Function*

**Description**

Computes cumulative time or cost for units m through n in a production block using Wright’s cumulative average model. Assumes the block begins at unit m and ends at unit n.

**Usage**

```r
callback(t, n, r, m = 1, na.rm = FALSE)
```

**Arguments**

- **t**: time (or cost) required for the mth unit of production
- **n**: last unit of the production block of concern
- **r**: learning curve rate
- **m**: first unit of the production block of concern (default: m = 1)
- **na.rm**: Should NA values be removed?

**Examples**

```r
# Production of the first 200 units of a product is nearing its
# end. Your customer said he is willing to buy an additional 50
# units. There will be no break in production or in learning. The
# first unit required 75 hours and the first 200 units had an 85%
# learning curve. How many hours will the second block of 50 units
# require?
```
ca_block(t = 75, m = 201, n = 250, r = .85)
## [1] 806.772

---

### ca_unit

**Wright’s Cumulative Average Unit Learning Curve Function**

**Description**
Computes the time (or cost) required for a specific unit using Wright’s cumulative average model.

**Usage**

```r
ca_unit(t, n, r, m = 1, na.rm = FALSE)
```

**Arguments**

- `t`: time (or cost) required for the mth unit of production
- `n`: nth unit you wish to predict the time (or cost) for
- `r`: learning curve rate
- `m`: mth unit for which you have time (or cost) information (default is m = 1)
- `na.rm`: Should NA values be removed?

**Examples**

```r
# An estimator want to know the unit hours for unit 2,200 using
# when the hours for unit 1 were 110 and the learning rate was
# 88.5%.
ca_unit(t = 110, m = 1, n = 2200, r = .885)
## [1] 23.34001
```

---

### cum_error

**Approximate Prediction Error**

**Description**
Computes approximate percent error in cumulative time (or cost) due to an incorrect choice of learning curve rate. The output provides the measure of error when learning curve r1 is erroneously chosen when r2 should have been chosen. It is the ratio of the actual cumulative results based on the realized learning curve to the predicted cumulative results based on the erroneously used learning rate.
delta

Usage
cum_error(n, r1, r2)

Arguments

- n: cumulative units in the production quantity
- r1: original learning curve rate (aka erroneously used learning curve rate)
- r2: learning curve rate to compare to r1 (aka realized learning curve rate)

Examples

# An estimator is predicting hours for a block of 250 units. Historically, # the organization has had a learning rate between 85-87%. What is the # potential error in the prediction by using one of these two learning # rates (85% vs. 87%)? If you go with a learning rate of 85% and the # organization performs at a learning rate of 87% then the error would # be 20%.

cum_error(n = 250, r1 = .85, r2 = .87)
## [1] 0.2035303

---

delta

Crawford vs. Wright Unit Difference

Description

Computes the difference between the unit or cumulative prediction estimates provided by the Crawford and Wright models.

Usage

delta(t, m, n, r, level = "u")

Arguments

- t: time (or cost) required to produce the first unit
- m: mth unit for which you have time (or cost) information (default is m = 1)
- n: the nth unit you wish to predict the time (or cost) for when comparing unit predictions or the last unit in the block when comparing cumulative time (or costs)
- r: learning curve rate
- level: calculate unit ("u") versus cumulative ("c") differences (default = "u")
Examples

# The first unit of production is expected to require 50 hours and
# the learning rate is expected to be 88.5%. However, the estimator
# is not sure whether the learning rate is based on the unit model
# or cumulative average model and wants to understand the difference
# between potential outcomes for each unit.

# differences between per unit time requirements
delta(t = 50, m = 1, n = 25, r = .885)
## [1] 0.000000 5.750000 6.103821 6.110269 6.041146 5.953271 5.863560 5.777401 5.696436
## [10] 5.620942 5.580687 5.485263 5.424223 5.367136 5.313606 5.263280 5.215844 5.171025
## [19] 5.128579 5.088293 5.049980 5.013473 4.978624 4.945304 4.913395

# differences between cumulative unit time requirements
delta(t = 50, m = 1, n = 25, r = .885, level = “c”)
## [1] 0.000000 5.750000 11.853822 17.964341 24.005492 29.958750 35.822324 41.599717
## [9] 47.296156 52.917196 58.467783 63.953805 69.377274 74.744400 80.058001 85.321298
## [17] 90.537136 95.708166 100.836748 105.925032 110.975601 115.988848 120.967115 125.912415
## [25] 130.825810

---

lc_rate  
Learning Rate Converter

Description

Computes the learning rate for given natural slopes

Usage

lc_rate(b, na.rm = FALSE)

Arguments

b          natural slope
na.rm      Should NA values be removed?

Examples

# Calculate the learning rates for natural slopes -.19, -.22, -.25
lc_rate(b = c(-.19, -.22, -.25))
## [1] 0.8766057 0.8585654 0.8408964
**lc_rate_est**  
*Learning Rate Estimate*

**Description**

Computes the learning rate based on total time (cost) to produce the first \( n \) units, time (cost) required for the first unit and total units produced.

**Usage**

\[
\text{lc_rate_est}(T, t, n)
\]

**Arguments**

- **T**: total time (or cost) required to produce the first \( n \) units
- **t**: time (or cost) required to produce the first unit
- **n**: total \( n \) units produced

**Examples**

```
# Estimate the learning curve rate for 250 units when the time
# for unit one took 80 hours and the total time for all 250
# units took 8,250 hours.

lc_rate_est(T = 8250, t = 80, n = 250)
# [1] 0.8947908
```

**natural_slope**  
*Natural Slope Rate Converter*

**Description**

Computes the natural slope rate for given learning rates

**Usage**

\[
\text{natural_slope}(r, \text{na.rm} = \text{FALSE})
\]

**Arguments**

- **r**: learning curve rate
- **na.rm**: Should NA values be removed?
Examples

# Calculate the natural slope for learning rates of 80%, 85%, 90%

natural_slope(r = c(.80, .85, .90))
## [1] -0.3219281 -0.2344653 -0.1520031

natural_slope_est   Natural Slope Estimate

Description

Computes the natural slope based on total time (cost) to produce the first n units, time (cost) required for the first unit and total units produced.

Usage

natural_slope_est(T, t, n)

Arguments

T     total time (or cost) required to produce the first n units
t     time (or cost) required to produce the first unit
n     total n units produced

Examples

# Estimate the natural slope for 250 units when the time for unit # one took 80 hours and the total time for all 250 units took # 8,250 hours.

natural_slope_est(T = 8250, t = 80, n = 250)
## [1] -0.1603777

plot_block_summary   Block Summary Plot

Description

Plots the Crawford unit learning curve for the production block containing units m through n (inclusive) while highlighting midpoint values.

Usage

plot_block_summary(t, m, n, r)
Arguments

t  time (or cost) required for the mth unit of production
m  mth unit for which you have time (or cost) information (default is \( m = 1 \))
n  nth (last) unit of production in the production block of concern (\( n > m \))
r  learning curve rate

Examples

```r
# A production block runs from unit 201 to unit 500 inclusive.
# The 201st unit had a required time of 125 hours with a 75%
# learning curve. Plot the block summary?

plot_block_summary(t = 125, m = 201, n = 500, r = .75)
```

---

**plot_delta**  
*Crawford vs. Wright Delta Plot*

Description

Plots the delta of hours (or cost) per unit between Crawford’s unit model and Wright’s cumulative average model.

Usage

`plot_delta(t, m, n, r, level = "u")`

Arguments

t  time (or cost) required to produce the mth unit
m  mth unit for which you have time (or cost) information (default is \( m = 1 \))
n  the nth unit you wish to predict the time (or cost) for when comparing unit predictions or the last unit in the block when comparing cumulative time (or costs)
r  learning curve rate
level  plot the delta between the Crawford and Wright models at the unit ("u") or cumulative ("c") level
Examples

# The first unit of production is expected to require 50 hours and
# the learning rate is expected to be 88.5%. However, the estimator
# is not sure whether the learning rate is based on the unit model
# or cumulative average model and wants to understand the difference
# between potential outcomes for each unit.

# Plot the differences between per unit time requirements
plot_delta(t = 50, m = 1, n = 25, r = .885)

# Plot the differences between cumulative time requirements
plot_delta(t = 50, m = 1, n = 25, r = .885, level = "c")

plot_unit_curve Learning Curve Plot

Description

Plots the learning curve for units m through n. Allows you to choose between the Crawford and Wright models and also between a unit level plot or a cumulative level plot.

Usage

plot_unit_curve(t, m, n, r, model = "u", level = "u")

Arguments

t time (or cost) required for the mth unit of production
m mth unit for which you have time (or cost) information (default is m = 1)
n nth unit of production you wish to plot the learning curve through (n > m)
r learning curve rate
model choose between the Crawford ("u") or Wright ("ca") models or plot both models with "both"
level plot the learning curve at the unit ("u") or cumulative ("c") level

Examples

# library(learningCurve)
# An estimator wants to plot the learning curve for for units
# one through 125 where the first unit requires 100 hours and
# the learning rate is 85%.

# plot the time (or cost) per unit based on Crawford's Unit
# Learning Curve Function
plot_unit_curve(t = 100, m = 1, n = 125, r = .85)
# Unit Block Summary Function

## Description

Provides summary information for the block containing units m through n (where n > m). Based on Crawford's unit learning curve model.

## Usage

```r
unit_block_summary(t, m, n, r, na.rm = FALSE)
```

## Arguments

- `t` : time for the mth unit
- `m` : lower bound unit of production block
- `n` : upper bound unit of production block
- `r` : learning curve rate
- `na.rm` : Should NA values be removed?

## Examples

```r
# A production block runs from unit 201 to unit 500 inclusive.
# The 201st unit had a required time of 125 hours with a 75%
# learning curve, what is the block summary?

unit_block_summary(t = 125, m = 201, n = 500, r = .75)

## 'block units'
## [1] 300

## 'block hours'
## [1] 30350.48

## 'midpoint unit'
## [1] 334.6103
```
## unit_cum_appx

### Description

Provides the approximate cumulative time or cost required for units m through n (inclusive) using the Crawford unit model. Provides nearly the exact output as unit_cum_exact(), usually only off by 1-2 units but reduces computational time drastically if trying to calculate cumulative hours (costs) for over a million units.

### Usage

```
unit_cum_appx(t, n, r, m = 1, na.rm = FALSE)
```

### Arguments

- `t`: time (or cost) required for the mth unit of production
- `n`: The unit you wish to predict the cumulative time (or cost) to
- `r`: learning curve rate
- `m`: mth unit of production (default set to 1st production unit)
- `na.rm`: Should NA values be removed?

### Examples

```r
library(learningCurve)
# An estimator believes that the first unit of a product will # require 100 labor hours. How many total hours will be required # for 125 units given the organization has historically experienced # an 85% learning curve?

unit_cum_appx(t = 100, n = 125, r = .85)
## [1] 5202.998

# Computational difference between unit_cum_exact() and unit_cum_appx() # for 1 million units

system.time(unit_cum_exact(t = 100, n = 1000000, r = .85))
## user  system elapsed
## 0.105 0.004  0.109

system.time(unit_cum_appx(t = 100, n = 1000000, r = .85))
## user  system elapsed
## 0.0    0.0    0.0
```
**unit_cum_exact**

*Exact Cumulative Unit Learning Curve Function*

**Description**

Provides the exact cumulative time or cost required for units m through n (inclusive) using the Crawford unit model.

**Usage**

```
unit_cum_exact(t, n, r, m = 1, na.rm = FALSE)
```

**Arguments**

- `t`: time (or cost) required for the mth unit of production.
- `n`: the unit you wish to predict the cumulative time (or cost) to.
- `r`: learning curve rate.
- `m`: mth unit of production (default set to 1st production unit).
- `na.rm`: Should NA values be removed?

**Examples**

```r
library(learningCurve)
# An estimator believes that the first unit of a product will
# require 100 labor hours. How many total hours will be required
# for 125 units given the organization has historically experienced
# an 85% learning curve?

unit_cum_exact(t = 100, n = 125, r = .85)
```

```
[1] 5201.085
```

---

**unit_curve**

*Crawford's Unit Learning Curve Function*

**Description**

Predicts the time or cost of the nth unit given the time of the mth unit and the learning rate.

**Usage**

```
unit_curve(t, n, r, m = 1, na.rm = FALSE)
```

**Examples**

```r
library(learningCurve)
# An estimator believes that the first unit of a product will
# require 100 labor hours. How many total hours will be required
# for 125 units given the organization has historically experienced
# an 85% learning curve?

unit_curve(t = 100, n = 125, r = .85)
```

```
[1] 5201.085
```
Arguments

\[ t \] time (or cost) required for the \( m \)th unit of production

\[ n \] \( n \)th unit you wish to predict the time (or cost) for

\[ r \] learning curve rate

\[ m \] \( m \)th unit of production (default set to 1st production unit)

\[ \text{na.rm} \] Should NA values be removed?

Examples

```r
library(learningCurve)
# An estimator believes that the first unit of a product will
# require 100 labor hours. How many hours will the 125th unit
# require given the organization has historically experienced
# an 85% learning curve?

unit_curve(t = 100, m = 1, n = 125, r = .85)
## [1] 32.23647

# If the estimator wants to assess the hours required for the
# 125 unit given multiple learning curve rates

r <- c(.8, .85, .9, .95)
unit_curve(t = 100, m = 1, n = 125, r = r)

# If the estimator has the time required for the 100th unit
unit_curve(t = 100, m = 100, n = 125, r = .85)
## [1] 94.90257
```

```
unit_midpoint
Midpoint Unit Function

Description

Provides the so-called "midpoint" or average unit between units \( m \) and \( n \) (where \( n > m \)). Based on Crawford's unit learning curve model.

Usage

unit_midpoint(m, n, r, na.rm = FALSE)

Arguments

\[ m \] lower bound unit of production

\[ n \] upper bound unit of production

\[ r \] learning curve rate

\[ \text{na.rm} \] Should NA values be removed?
Examples

# If a production block runs from unit 201 to unit 500 inclusive
# with a 75% learning curve, what is the midpoint unit?

unit_midpoint(m = 201, n = 500, r = .75)
## [1] 334.6103
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