Qualitative Comparative Analysis (QCA) Using R: A Beginner's Guide

Independent Exercise on a full QCA - Solution

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1. BEFORE THE ANALYTIC MOMENT

Load the packages:

```
library(SetMethods)
library(QCA)
```

The data comes from Paykani, Toktam, Rafiey, Hassan, Sajjadi, Homeira (2018) "A fuzzy set qualitative comparative analysis of 131 countries: Which configuration of the structural conditions can explain health better?" [https://pubmed.ncbi.nlm.nih.gov/29357889/]

Outcome: HL = High life expectancy

Conditions:

HE = High quality education GG = Good governance AH = Affluent health system HI = High income inequality HW = High wealth

Load the data:

```
data("PAYF")
head(PAYF)
```

```
##       COUNTRY                 REGION   HE   GG   AH   HI   HW   HL   LL
## ALB   Albania        European Region 0.33 0.47 0.32 0.14 0.41 0.84 0.16
## AGO    Angola         African Region 0.00 0.00 0.04 1.00 0.13 0.00 1.00
## ARG Argentina Region of the Americas 0.82 0.36 0.68 0.93 0.78 0.67 0.33
## ARM   Armenia        European Region 0.32 0.42 0.68 0.02 0.20 0.46 0.54
## AUS Australia Western Pacific Region 1.00 0.99 0.99 0.11 0.99 0.99 0.01
## AUT   Austria        European Region 0.99 0.99 1.00 0.04 1.00 0.98 0.02
```

Store condition names in one object in order to save time and space:

```
conds <- c("HE", "GG", "AH", "HI","HW")
```

The data is already calibrated, therefore we can perform some diagnostics tests

Check the skewness of the data for the 5 conditions and the outcome HL:

```
skew.check(PAYF[, 3:8])
```

```
## [1] "Set HE - Cases > 0.5 / Total number of cases: 58 / 131 = 44.27 %"
## [2] "Set GG - Cases > 0.5 / Total number of cases: 64 / 131 = 48.85 %"
## [3] "Set AH - Cases > 0.5 / Total number of cases: 56 / 131 = 42.75 %"
## [4] "Set HI - Cases > 0.5 / Total number of cases: 65 / 131 = 49.62 %"
## [5] "Set HW - Cases > 0.5 / Total number of cases: 64 / 131 = 48.85 %"
## [6] "Set HL - Cases > 0.5 / Total number of cases: 52 / 131 = 39.69 %"
```

Check whether there are any ambiguous cases with set-membership scores of 0.5 in any of the 5 conditions and the outcome HL:

```
ambig.cases(PAYF[, 3:8])
```

```
## [1] "There are no cases with fuzzy-set scores of 0.5."
```

2. NECESSITY ANALYSIS FOR THE PRESENCE OF THE OUTCOME

Check whether we have any single necessary conditions for outcome HL:

```
QCAfit(PAYF[, 3:7],
       PAYF$HL,
       necessity = TRUE)
```

```
##     Cons.Nec Cov.Nec   RoN
## HE     0.885   0.800 0.845
## GG     0.858   0.761 0.815
## AH     0.790   0.756 0.833
## HI     0.433   0.383 0.629
## HW     0.897   0.799 0.841
## ~HE    0.338   0.280 0.560
## ~GG    0.342   0.288 0.571
## ~AH    0.382   0.300 0.540
## ~HI    0.704   0.595 0.702
## ~HW    0.340   0.285 0.568
```

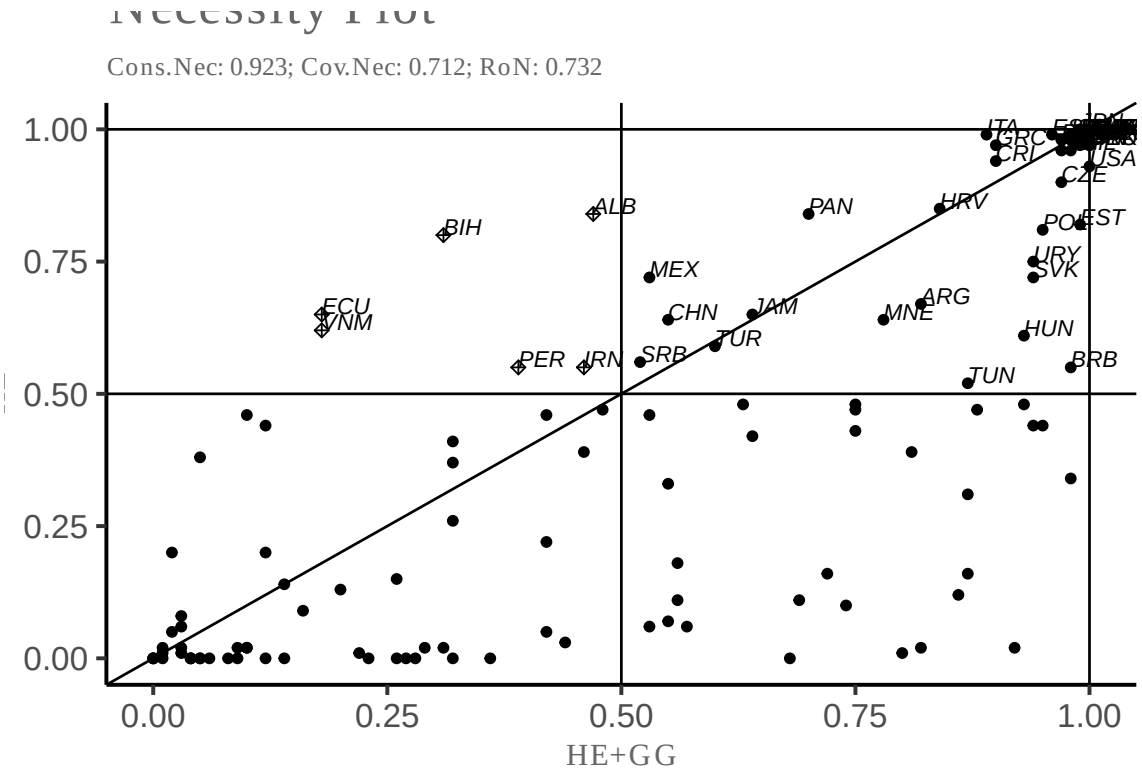
Display SUIN conditions, setting the inclusion cutoff to 0.9, coverage cutoff to 0.6, and RoN to 0.5. Display only the combinations of a maximum of two conditions.

```
SUIN_y <- superSubset(data = PAYF,
                      outcome  = "HL",
                      conditions = conds,
                      incl.cut = 0.9,
                      cov.cut = 0.6,
                      ron.cut = 0.5,
                      depth = 2)
SUIN_y
```

```
##
##            inclN   RoN   covN
## ------------------------------
## 1  HE+GG   0.923  0.732  0.712
## 2  HE+AH   0.906  0.748  0.719
## 3  HE+~HI  0.924  0.595  0.621
## 4  HE+HW   0.928  0.774  0.747
## 5  GG+AH   0.906  0.698  0.680
## 6  GG+HW   0.934  0.732  0.716
## 7  AH+HW   0.916  0.751  0.724
## 8  ~HI+HW  0.941  0.577  0.618
## ------------------------------
```

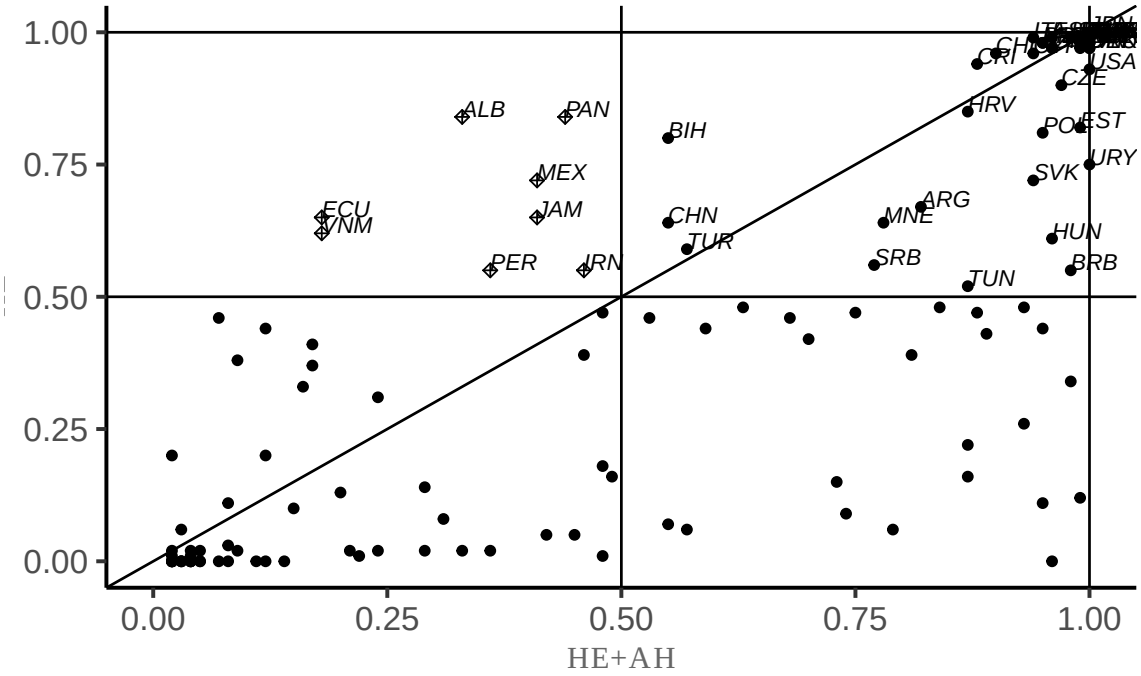
Plot the results:

```
pimplot(data = PAYF,
            outcome = "HL",
            results = SUIN_y,
            necessity = TRUE)
```



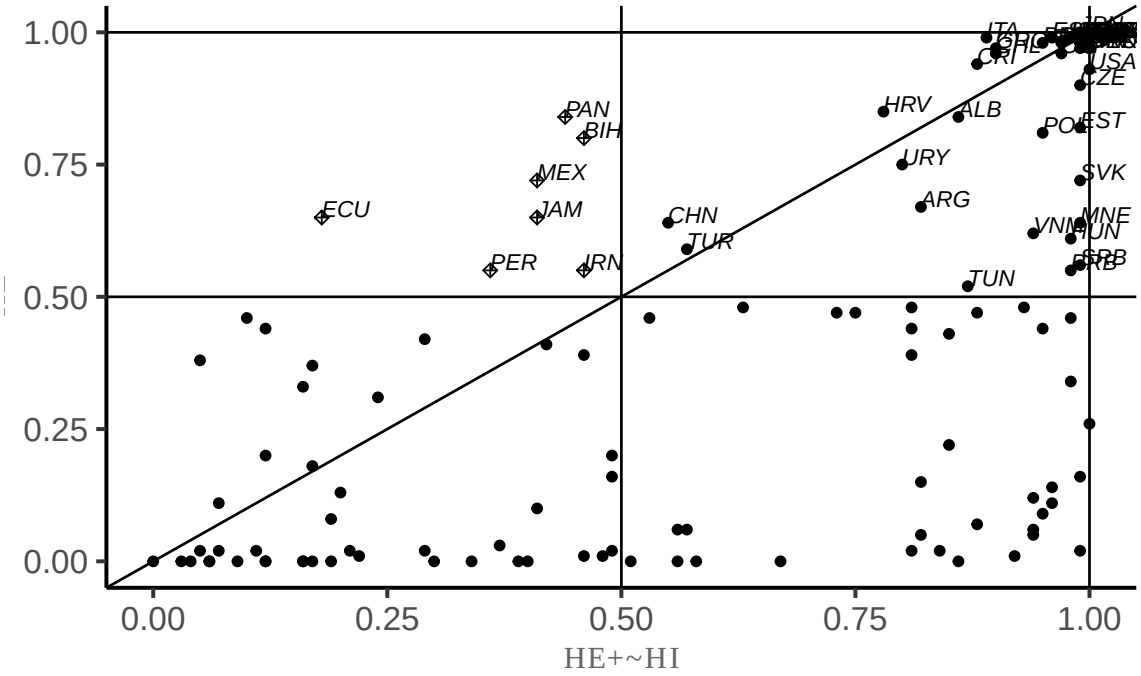
Necessity Plot

Cons.Nec: 0.906; Cov.Nec: 0.719; RoN: 0.748



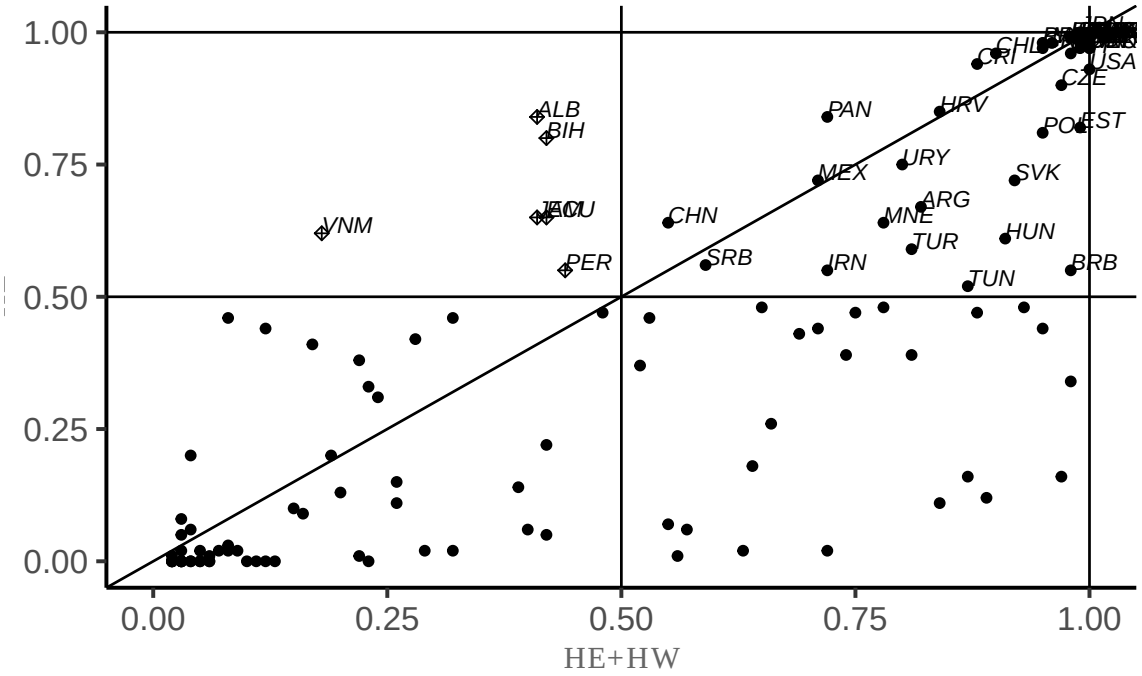
Necessity Plot

Cons.Nec: 0.924; Cov.Nec: 0.621; RoN: 0.595



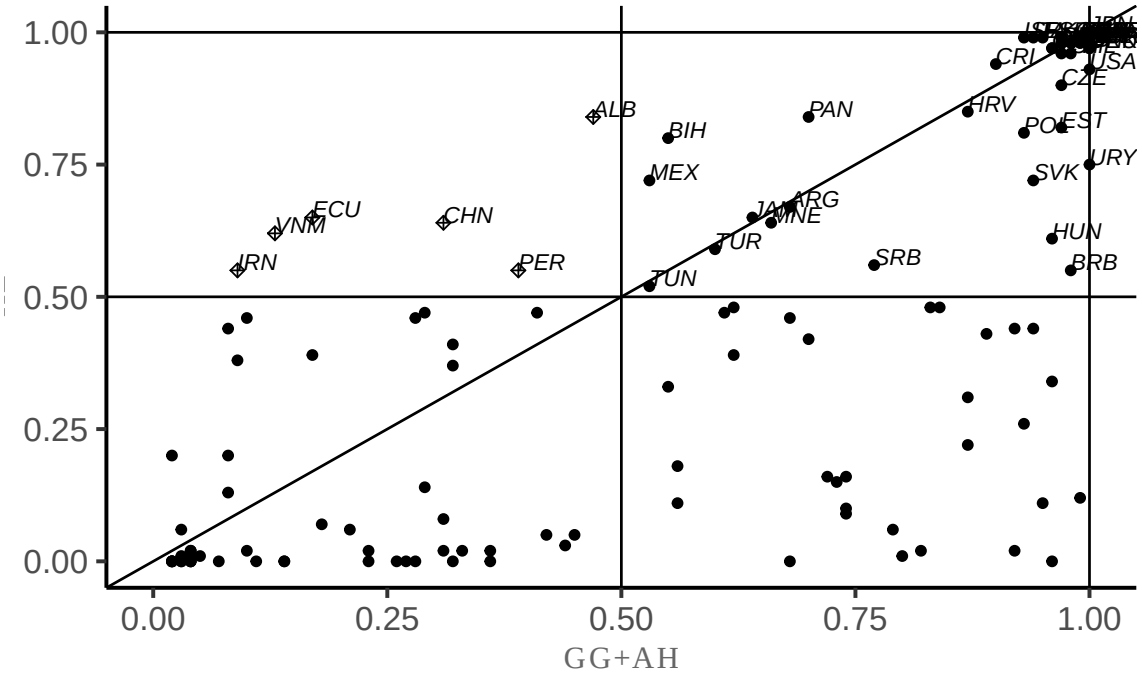
Necessity Plot

Cons.Nec: 0.928; Cov.Nec: 0.747; RoN: 0.774



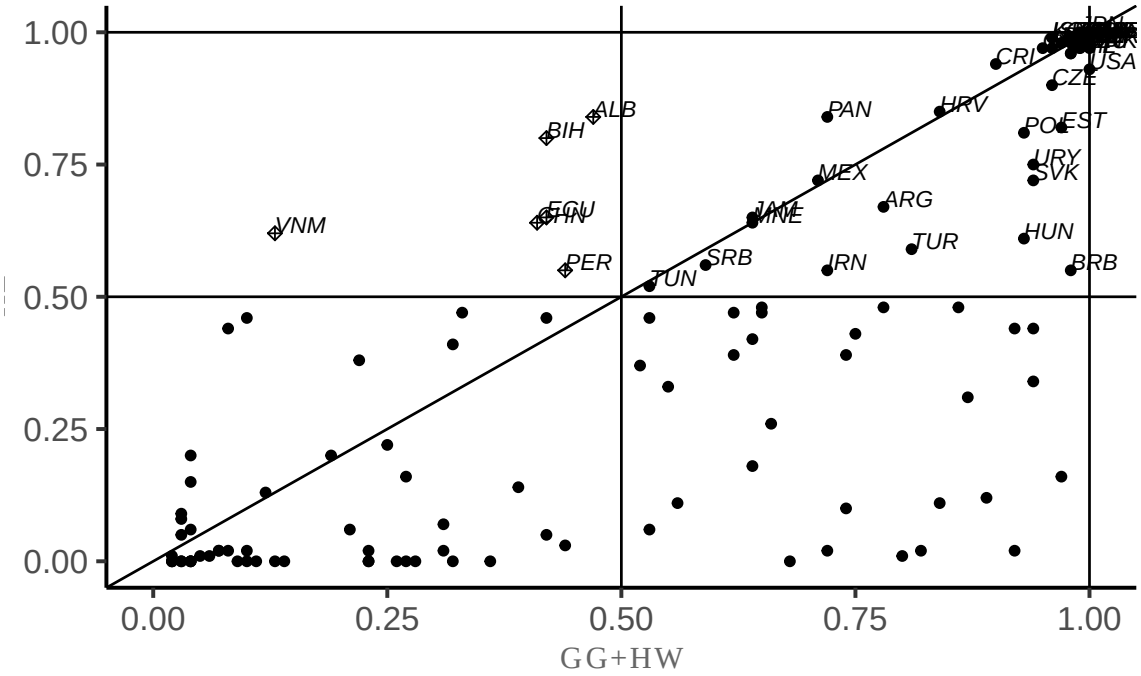
Necessity Plot

Cons.Nec: 0.906; Cov.Nec: 0.680; RoN: 0.698



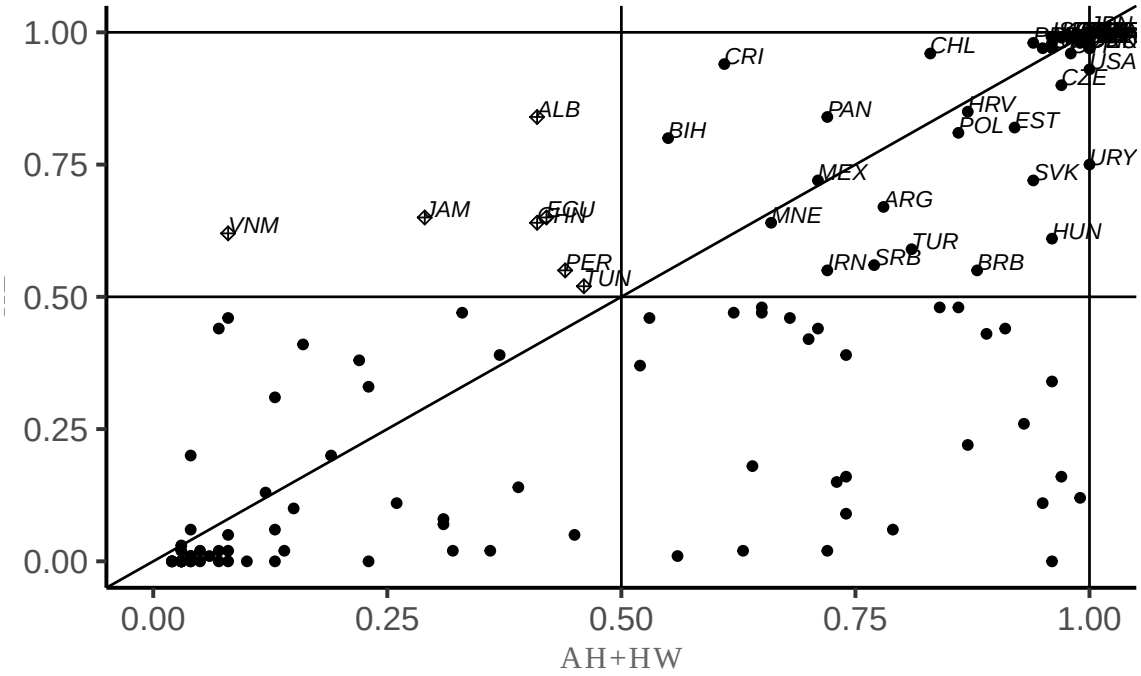
Necessity Plot

Cons.Nec: 0.934; Cov.Nec: 0.716; RoN: 0.732



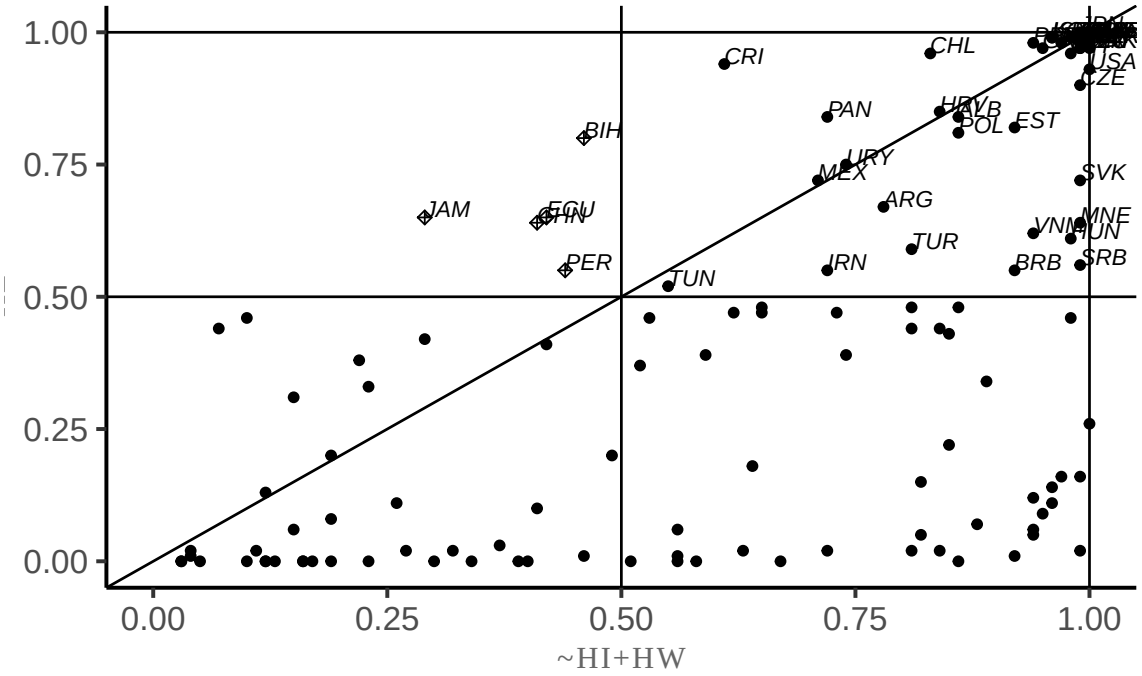
Necessity Plot

Cons.Nec: 0.916; Cov.Nec: 0.724; RoN: 0.751



Necessity Plot

Cons.Nec: 0.941; Cov.Nec: 0.618; RoN: 0.577



3. SUFFICIENCY ANALYSIS FOR THE PRESENCE OF THE OUTCOME

Truth Table

Create the truth table, setting the inclusion cutoff to 0.84 and the number of cases needed to include a row in the minimization to 1.

```
TT_y <- truthTable(data = PAYF,
                   outcome  = "HL",
                   conditions = conds,
                   incl.cut = 0.84,
                   n.cut = 1,
                   sort.by = c("OUT", "incl"),
                   complete = TRUE,
                   show.cases = FALSE)
TT_y
```

```
##
##   OUT: output value
##     n: number of cases in configuration
##  incl: sufficiency inclusion score
##   PRI: proportional reduction in inconsistency
##
##       HE GG AH HI HW   OUT    n   incl  PRI
## 30    1  1  1  0  1     1     36  0.929 0.906
## 32    1  1  1  1  1     1     5   0.925 0.824
## 24    1  0  1  1  1     1     2   0.890 0.470
## 20    1  0  0  1  1     1     2   0.873 0.281
## 14    0  1  1  0  1     1     1   0.868 0.435
## 26    1  1  0  0  1     1     1   0.855 0.375
## 13    0  1  1  0  0     1     1   0.850 0.248
## 28    1  1  0  1  1     1     4   0.846 0.525
## 19    1  0  0  1  0     0     2   0.809 0.173
```

```
## 25   1  1  0  0  0     0     2   0.807 0.192
## 15   0  1  1  1  0     0     1   0.806 0.215
## 21   1  0  1  0  0     0     1   0.785 0.145
##  4   0  0  0  1  1     0     4   0.765 0.219
##  6   0  0  1  0  1     0     1   0.755 0.228
## 22   1  0  1  0  1     0     2   0.753 0.209
## 17   1  0  0  0  0     0     1   0.747 0.110
## 12   0  1  0  1  1     0     6   0.734 0.248
##  7   0  0  1  1  0     0     2   0.703 0.151
##  5   0  0  1  0  0     0     4   0.617 0.100
## 11   0  1  0  1  0     0     7   0.537 0.083
##  1   0  0  0  0  0     0    16   0.361 0.060
##  3   0  0  0  1  0     0    30   0.332 0.036
##  2   0  0  0  0  1     ?     0     -     -
##  8   0  0  1  1  1     ?     0     -     -
##  9   0  1  0  0  0     ?     0     -     -
## 10   0  1  0  0  1     ?     0     -     -
## 16   0  1  1  1  1     ?     0     -     -
## 18   1  0  0  0  1     ?     0     -     -
## 23   1  0  1  1  0     ?     0     -     -
## 27   1  1  0  1  0     ?     0     -     -
## 29   1  1  1  0  0     ?     0     -     -
## 31   1  1  1  1  0     ?     0     -     -
```

Logical Minimization

Produce the conservative solution:

```
sol_yc <- minimize(TT_y,
                   details = TRUE)
sol_yc
```

```
##
## M1: HE*GG*HW + HE*HI*HW + ~HE*GG*AH*~HI -> HL
##
##                    inclS   PRI   covS   covU
## ------------------------------------------
## 1        HE*GG*HW  0.901  0.864  0.800  0.473
## 2        HE*HI*HW  0.862  0.688  0.334  0.043
## 3  ~HE*GG*AH*~HI  0.844  0.373  0.134  0.011
## ------------------------------------------
##                M1  0.885  0.837  0.855
```

Produce the most parsimonious solution:

```
sol_yp <- minimize(TT_y,
                   details = TRUE,
                   include = "?")
sol_yp
```

```
##
## M1: ~HE*GG*~HI + HE*GG*HW + HE*HI*HW -> HL
## M2: ~HE*GG*~HI + HE*HI*HW + GG*~HI*HW -> HL
## M3: HE*GG*HW + HE*HI*HW + GG*AH*~HI -> HL
## M4: HE*~AH*HW + HE*AH*HI + GG*AH*~HI -> HL
## M5: HE*~AH*HW + HE*HI*HW + GG*AH*~HI -> HL
## M6: HE*~AH*HW + GG*AH*~HI + AH*HI*HW -> HL
## M7: HE*HI*HW + GG*AH*~HI + GG*~HI*HW -> HL
## M8: HE*HI*HW + GG*AH*~HI + ~AH*~HI*HW -> HL
##
##
##                                ------------------------------------------------
```

```
##                inclS   PRI   covS   covU   (M1)   (M2)   (M3)   (M4)   (M5)   (M6)
## ------------------------------------------------------------------------------------
## 1  ~HE*GG*~HI  0.670  0.190  0.151  0.005  0.018  0.014
## 2    HE*GG*HW  0.901  0.864  0.800  0.034  0.472         0.039
## 3   HE*~AH*HW  0.828  0.463  0.270  0.000                       0.094  0.006  0.094
## 4    HE*AH*HI  0.908  0.777  0.252  0.002                       0.044
## 5    HE*HI*HW  0.862  0.688  0.334  0.000  0.043  0.172  0.043         0.042
## 6   GG*AH*~HI  0.908  0.878  0.631  0.000                0.013  0.452  0.454  0.453
## 7   GG*~HI*HW  0.910  0.879  0.644  0.001         0.440
## 8  ~AH*~HI*HW  0.748  0.266  0.149  0.001
## 9    AH*HI*HW  0.855  0.684  0.251  0.001                                       0.045
## ------------------------------------------------------------------------------------
##            M1  0.848  0.787  0.862
##            M2  0.847  0.782  0.830
##            M3  0.878  0.827  0.857
##            M4  0.882  0.828  0.826
##            M5  0.879  0.825  0.824
##            M6  0.868  0.810  0.827
##            M7  0.880  0.828  0.824
##            M8  0.864  0.805  0.828
##
## ---------------------------
##                (M7)   (M8)
## ---------------------------
## 1  ~HE*GG*~HI
## 2    HE*GG*HW
## 3   HE*~AH*HW
## 4    HE*AH*HI
## 5    HE*HI*HW  0.172  0.169
## 6   GG*AH*~HI  0.008  0.453
## 7   GG*~HI*HW  0.007
## 8  ~AH*~HI*HW         0.011
## 9    AH*HI*HW
## ---------------------------
```

Check the simplifying assumptions:

```
sol_yp$SA
```

```
## $M1
##    HE GG AH HI HW
## 9   0  1  0  0  0
## 10  0  1  0  0  1
##
## $M2
##    HE GG AH HI HW
## 9   0  1  0  0  0
## 10  0  1  0  0  1
##
## $M3
##    HE GG AH HI HW
## 29  1  1  1  0  0
##
## $M4
##    HE GG AH HI HW
## 18  1  0  0  0  1
## 23  1  0  1  1  0
## 29  1  1  1  0  0
## 31  1  1  1  1  0
##
## $M5
```

```
##    HE GG AH HI HW
## 18  1  0  0  0  1
## 29  1  1  1  0  0
##
## $M6
##    HE GG AH HI HW
## 8   0  0  1  1  1
## 16  0  1  1  1  1
## 18  1  0  0  0  1
## 29  1  1  1  0  0
##
## $M7
##    HE GG AH HI HW
## 10  0  1  0  0  1
## 29  1  1  1  0  0
##
## $M8
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 10  0  1  0  0  1
## 18  1  0  0  0  1
## 29  1  1  1  0  0
```

Produce the intermediate solution with the following directional expectations 1, 1, 1, 0, 1

```
sol_yi <- minimize(TT_y,
                   details = TRUE,
                   include = "?",
                   dir.exp = c(1, 1, 1, 0, 1))
sol_yi
```

```
##
## From C1P1, C1P2:
##
## M1:    HE*GG*HW + HE*HI*HW + ~HE*GG*AH*~HI -> HL
##
##                    inclS   PRI   covS   covU
## ------------------------------------------------
## 1       HE*GG*HW  0.901  0.864  0.800  0.473
## 2       HE*HI*HW  0.862  0.688  0.334  0.043
## 3  ~HE*GG*AH*~HI  0.844  0.373  0.134  0.011
## ------------------------------------------------
##               M1  0.885  0.837  0.855
##
##
## From C1P3, C1P4, C1P5, C1P6, C1P7, C1P8:
##
## M1:    HE*GG*HW + HE*HI*HW + GG*AH*~HI -> HL
##
##                inclS   PRI   covS   covU
## ----------------------------------------
## 1   HE*GG*HW  0.901  0.864  0.800  0.039
## 2   HE*HI*HW  0.862  0.688  0.334  0.043
## 3  GG*AH*~HI  0.908  0.878  0.631  0.013
## ----------------------------------------
##           M1  0.878  0.827  0.857
```

Check the easy counterfactuals

```
sol_yi$i.sol$C1P1$EC
```

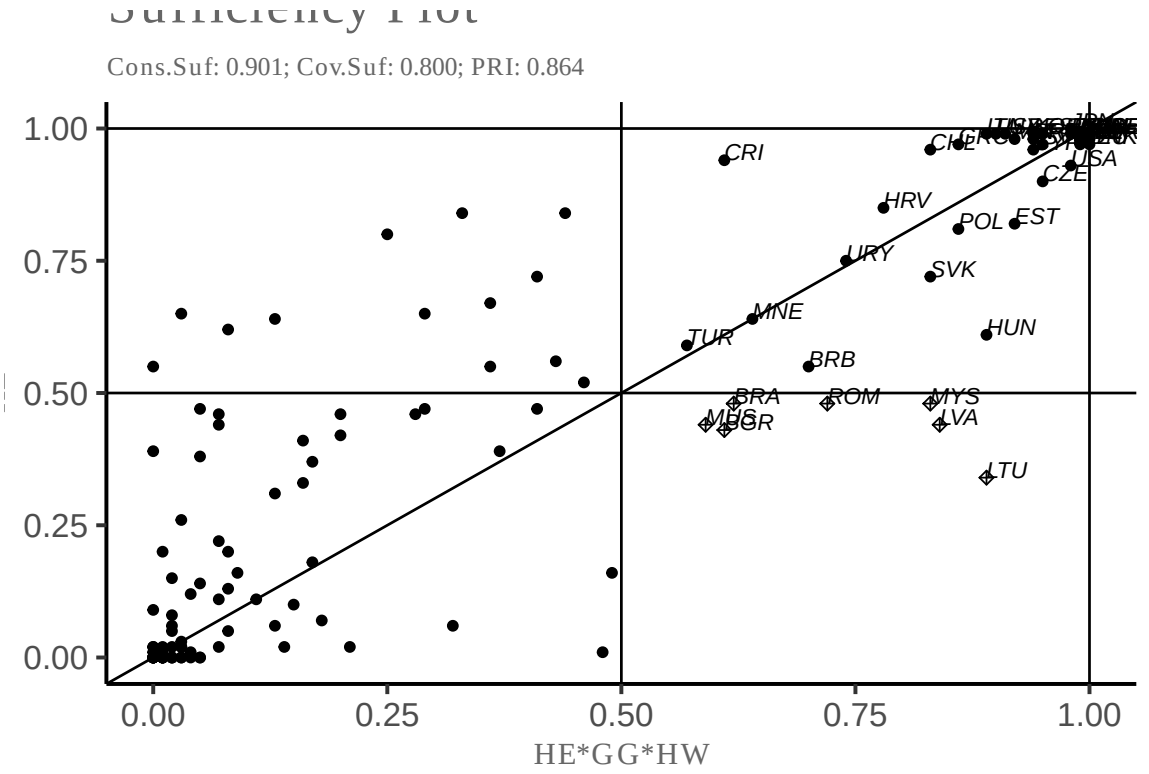
```
## [1] V1 V2 V3 V4 V5
```

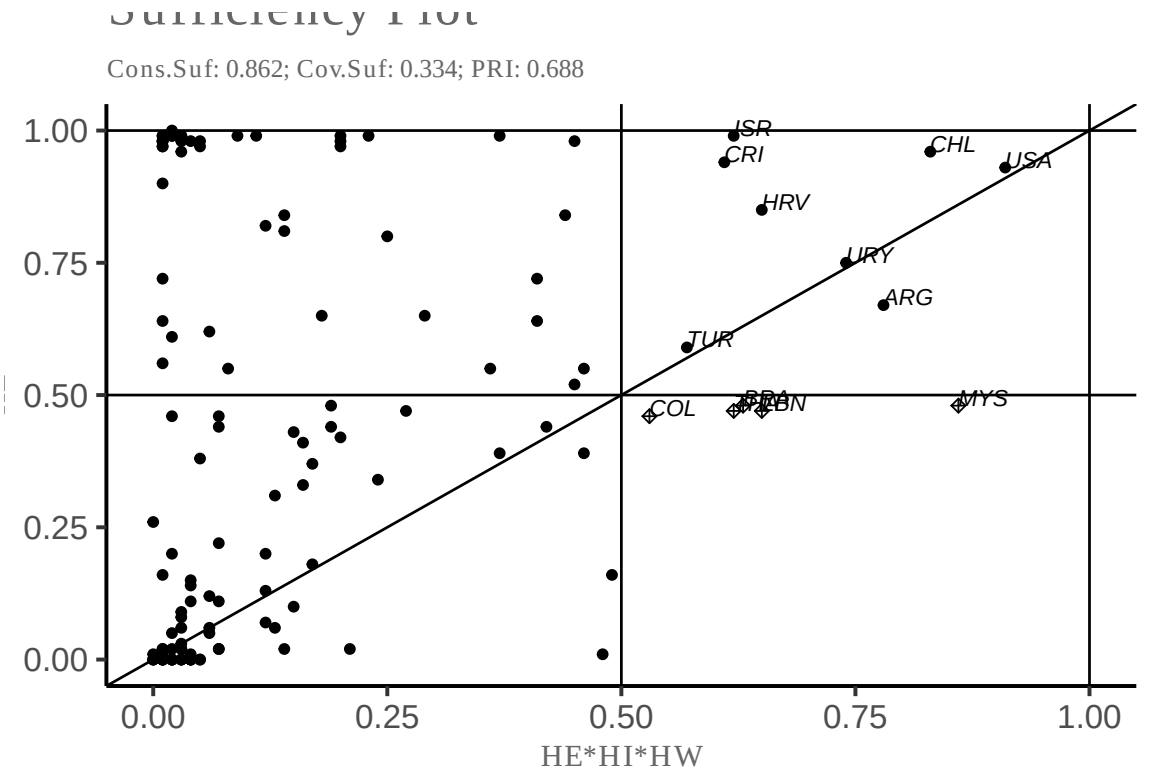
```
## <0 rows> (or 0-length row.names)
```

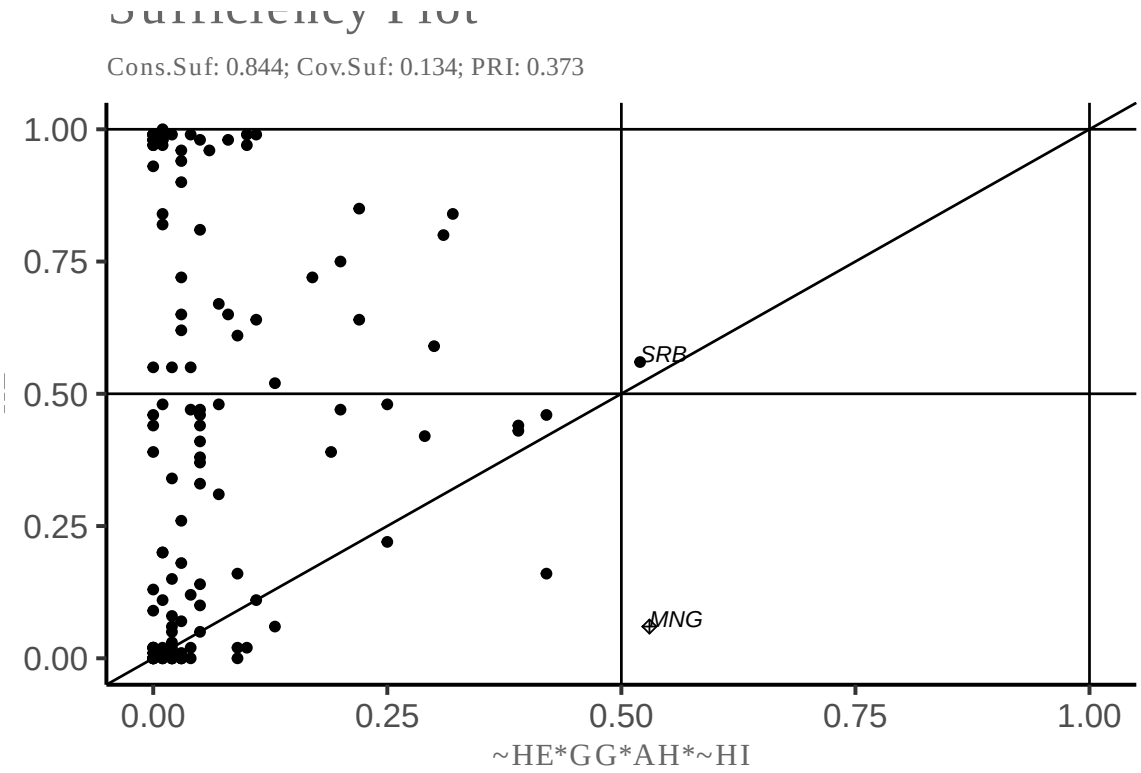
There are no easy counterfactuals

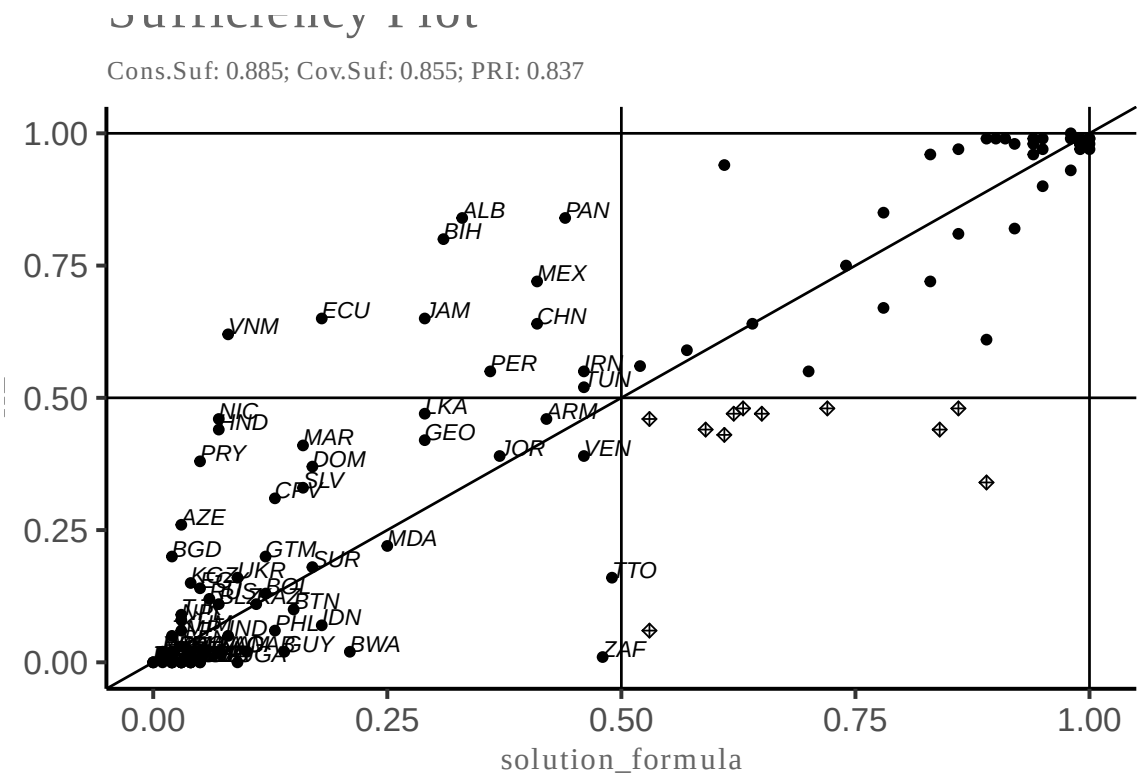
Plot the intermediate solution

```
pimplot(data = PAYF,
        results = sol_yi,
        outcome = "HL")
```









4. NECESSITY ANALYSIS FOR THE ABSENCE OF THE OUTCOME

Analyze necessary conditions for outcome ~Y using the superSubset function. Set inclusion cutoff to 0.908, depth to 2, coverage cutoff to 0.8 and RoN to 0.8.

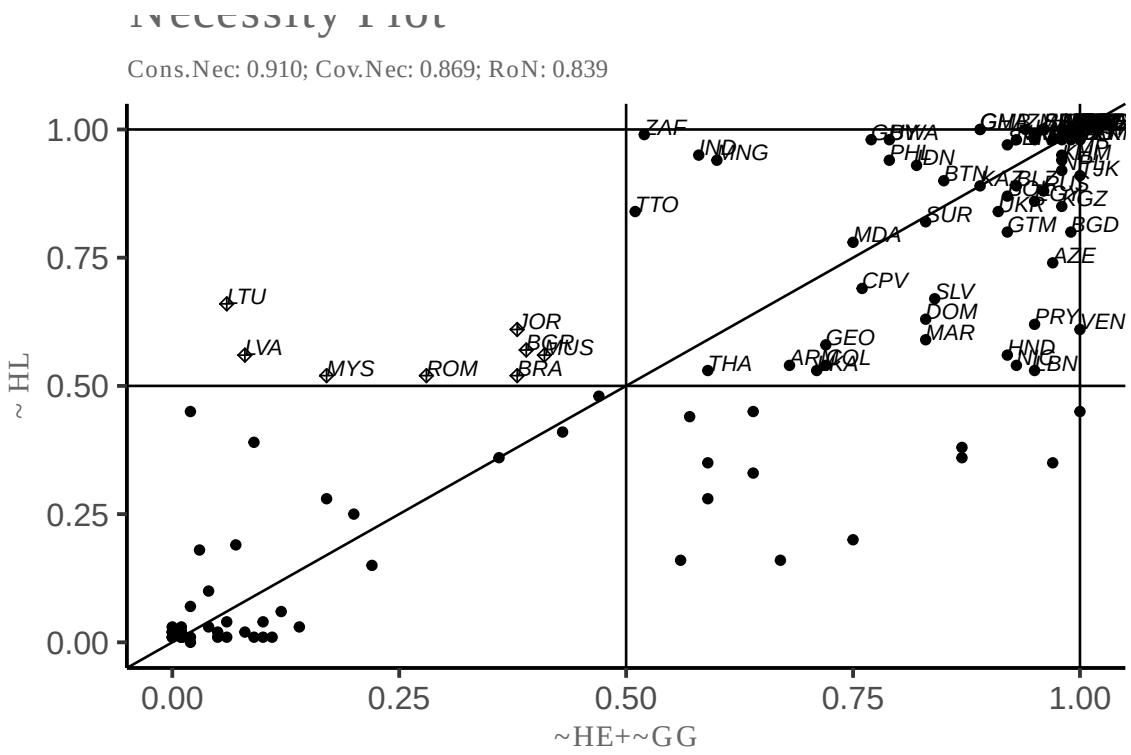
```
SUIN_ny <- superSubset(data = PAYF,
                       outcome  = "~HL",
                       conditions = conds,
```

```
                        incl.cut = 0.908,
                        cov.cut = 0.8,
                        ron.cut = 0.8,
                        depth = 2)
SUIN_ny
```

```
##
##              inclN   RoN   covN
## ------------------------------
## 1  ~HE+~GG  0.910  0.839  0.869
## ------------------------------
```

Plot the results:

```
pimplot(data = PAYF,
        outcome = "HL",
        results = SUIN_ny,
        necessity = TRUE)
```



5. SUFFICIENCY ANALYSIS FOR THE ABSENCE OF THE OUTCOME

Truth Table

Create a truth table setting the inclusion cutoff to 0.9 and the number of cases needed to include a row in the analysis to 2.

```
TT_ny <- truthTable(data = PAYF,
                        outcome  = "~HL",
                        conditions = conds,
                        incl.cut = 0.9,
                        n.cut = 2,
                        sort.by = c("OUT", "incl"),
                        complete = TRUE)
TT_ny
```

```
##
##   OUT: output value
##     n: number of cases in configuration
##  incl: sufficiency inclusion score
##   PRI: proportional reduction in inconsistency
##
##      HE GG AH HI HW   OUT    n   incl  PRI
## 19   1  0  0  1  0     1     2   0.960 0.827
##  5   0  0  1  0  0     1     4   0.954 0.892
## 11   0  1  0  1  0     1     7   0.954 0.908
## 25   1  1  0  0  0     1     2   0.953 0.803
##  3   0  0  0  1  0     1     30  0.951 0.929
##  1   0  0  0  0  0     1     16  0.950 0.926
##  7   0  0  1  1  0     1     2   0.947 0.849
## 20   1  0  0  1  1     1     2   0.946 0.691
## 22   1  0  1  0  1     1     2   0.935 0.791
##  4   0  0  0  1  1     1     4   0.934 0.781
## 12   0  1  0  1  1     1     6   0.912 0.752
## 24   1  0  1  1  1     0     2   0.894 0.490
## 28   1  1  0  1  1     0     4   0.806 0.405
## 32   1  1  1  1  1     0     5   0.650 0.175
## 30   1  1  1  0  1     0     36  0.285 0.055
## 17   1  0  0  0  0     ?     1   0.969 0.890
## 21   1  0  1  0  0     ?     1   0.963 0.855
## 13   0  1  1  0  0     ?     1   0.950 0.752
## 15   0  1  1  1  0     ?     1   0.940 0.755
##  6   0  0  1  0  1     ?     1   0.927 0.772
## 26   1  1  0  0  1     ?     1   0.910 0.611
## 14   0  1  1  0  1     ?     1   0.898 0.565
##  2   0  0  0  0  1     ?     0     -     -
##  8   0  0  1  1  1     ?     0     -     -
##  9   0  1  0  0  0     ?     0     -     -
## 10   0  1  0  0  1     ?     0     -     -
## 16   0  1  1  1  1     ?     0     -     -
## 18   1  0  0  0  1     ?     0     -     -
## 23   1  0  1  1  0     ?     0     -     -
## 27   1  1  0  1  0     ?     0     -     -
## 29   1  1  1  0  0     ?     0     -     -
## 31   1  1  1  1  0     ?     0     -     -
```

Logical Minimization

Produce the most parsimonious solution:

```
sol_nyp <- minimize(TT_ny,
                    details = TRUE,
                    include = "?")
sol_nyp
```

```
##
## M1: ~HE + ~GG*~AH + ~GG*~HI + (~HW) -> ~HL
## M2: ~HE + ~GG*~AH + ~GG*~HI + (~AH*~HI) -> ~HL
##
##                                    -------------------
##              inclS   PRI   covS    covU   (M1)   (M2)
## ---------------------------------------------------
## 1       ~HE  0.905  0.877  0.832  0.029  0.033  0.129
## 2  ~GG*~AH  0.905  0.870  0.676  0.007  0.007  0.022
## 3  ~GG*~HI  0.927  0.897  0.398  0.021  0.021  0.033
## ---------------------------------------------------
```

```
## 4      ~HW  0.914  0.886  0.829  0.013  0.024
## 5  ~AH*~HI  0.918  0.878  0.332  0.004         0.014
## ------------------------------------------------------
##          M1  0.875  0.839  0.929
##          M2  0.882  0.848  0.919
```

Check the simplifying assumptions:

```
sol_nyp$SA
```

```
## $M1
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 8   0  0  1  1  1
## 9   0  1  0  0  0
## 10  0  1  0  0  1
## 13  0  1  1  0  0
## 14  0  1  1  0  1
## 15  0  1  1  1  0
## 16  0  1  1  1  1
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
## 23  1  0  1  1  0
## 27  1  1  0  1  0
## 29  1  1  1  0  0
## 31  1  1  1  1  0
##
## $M2
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 8   0  0  1  1  1
## 9   0  1  0  0  0
## 10  0  1  0  0  1
## 13  0  1  1  0  0
## 14  0  1  1  0  1
## 15  0  1  1  1  0
## 16  0  1  1  1  1
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
## 26  1  1  0  0  1
```

Produce the intermediate solution with the following direcional expectations 0, 0, 0, 1, 0:

```
sol_nyi <- minimize(TT_ny,
                    details = TRUE,
                    include = "?",
                    dir.exp = c(0, 0, 0, 1, 0))
sol_nyi
```

```
##
## From C1P1:
##
## M1:    ~GG*~AH + ~GG*~HI + ~AH*~HW + ~HE*~GG*~HW + ~HE*~AH*HI -> ~HL
##
##                 inclS   PRI   covS   covU
## ----------------------------------------
## 1      ~GG*~AH  0.905  0.870  0.676  0.010
## 2      ~GG*~HI  0.927  0.897  0.398  0.043
```

```
## 3      ~AH*~HW  0.920  0.894  0.735  0.042
## 4  ~HE*~GG*~HW  0.942  0.922  0.674  0.018
## 5   ~HE*~AH*HI  0.913  0.881  0.541  0.014
## ----------------------------------------
##             M1  0.887  0.854  0.893
##
##
## From C1P2:
##
## M1:    ~GG*~AH + ~GG*~HI + ~HE*~GG*~HW + ~HE*~AH*HI + ~AH*~HI*~HW -> ~HL
##
##                 inclS   PRI   covS   covU
## ----------------------------------------
## 1      ~GG*~AH  0.905  0.870  0.676  0.026
## 2      ~GG*~HI  0.927  0.897  0.398  0.043
## 3  ~HE*~GG*~HW  0.942  0.922  0.674  0.018
## 4   ~HE*~AH*HI  0.913  0.881  0.541  0.063
## 5  ~AH*~HI*~HW  0.937  0.904  0.312  0.012
## ----------------------------------------
##             M1  0.893  0.860  0.863
```

Check the easy counterfactuals

```
sol_nyi$i.sol$C1P1$EC
```

```
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 9   0  1  0  0  0
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
## 27  1  1  0  1  0
```

```
sol_nyi$i.sol$C1P2$EC
```

```
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 9   0  1  0  0  0
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
```

Look at the PI chart

```
sol_nyi$PIchart
```

```
##
##           1  3  4  5  7  11 12 19 20 22 25
## ~HE       x  x  x  x  x  x  x  -  -  -  -
## ~HW       x  x  -  x  x  x  -  x  -  -  x
## ~GG*~AH   x  x  x  -  -  -  -  x  x  -  -
## ~GG*~HI   x  -  -  x  -  -  -  -  -  x  -
## ~AH*~HI   x  -  -  -  -  -  -  -  -  -  x
```

6. ENHANCED STANDARD ANALYSIS FOR THE ABSENCE OF THE OUTCOME

Assumptions contradicting necessity

Let's use the intermediate solution

From SUIN_ny, we know that the expression $_{\text{HE+}}$GG contradicts the statement of necessity.

Does any of the simplifying assumptions for the most parsimonious solution contradict the statement of necessity?

```
sol_nyp$SA
```

```
## $M1
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 8   0  0  1  1  1
## 9   0  1  0  0  0
## 10  0  1  0  0  1
## 13  0  1  1  0  0
## 14  0  1  1  0  1
## 15  0  1  1  1  0
## 16  0  1  1  1  1
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
## 23  1  0  1  1  0
## 27  1  1  0  1  0
## 29  1  1  1  0  0
## 31  1  1  1  1  0
##
## $M2
##    HE GG AH HI HW
## 2   0  0  0  0  1
## 6   0  0  1  0  1
## 8   0  0  1  1  1
## 9   0  1  0  0  0
## 10  0  1  0  0  1
## 13  0  1  1  0  0
## 14  0  1  1  0  1
## 15  0  1  1  1  0
## 16  0  1  1  1  1
## 17  1  0  0  0  0
## 18  1  0  0  0  1
## 21  1  0  1  0  0
## 26  1  1  0  0  1
```

Create a new truth table which will set such rows to OUT=0, using the esa function

```
TT_ny_esa <- esa(TT_ny,
                 nec_cond = c("~HE+~GG"))
TT_ny_esa
```

```
##
##   OUT: output value
##     n: number of cases in configuration
##  incl: sufficiency inclusion score
##   PRI: proportional reduction in inconsistency
##
##      HE GG AH HI HW   OUT    n   incl  PRI
## 19   1  0  0  1  0     1     2   0.960 0.827
##  5   0  0  1  0  0     1     4   0.954 0.892
## 11   0  1  0  1  0     1     7   0.954 0.908
## 25   1  1  0  0  0     0     2   0.953 0.803
##  3   0  0  0  1  0     1     30  0.951 0.929
##  1   0  0  0  0  0     1     16  0.950 0.926
##  7   0  0  1  1  0     1     2   0.947 0.849
```

```
## 20   1  0  0  1  1     1     2   0.946 0.691
## 22   1  0  1  0  1     1     2   0.935 0.791
##  4   0  0  0  1  1     1     4   0.934 0.781
## 12   0  1  0  1  1     1     6   0.912 0.752
## 24   1  0  1  1  1     0     2   0.894 0.490
## 28   1  1  0  1  1     0     4   0.806 0.405
## 32   1  1  1  1  1     0     5   0.650 0.175
## 30   1  1  1  0  1     0    36   0.285 0.055
## 17   1  0  0  0  0     ?     1   0.969 0.890
## 21   1  0  1  0  0     ?     1   0.963 0.855
## 13   0  1  1  0  0     ?     1   0.950 0.752
## 15   0  1  1  1  0     ?     1   0.940 0.755
##  6   0  0  1  0  1     ?     1   0.927 0.772
## 26   1  1  0  0  1     0     1   0.910 0.611
## 14   0  1  1  0  1     ?     1   0.898 0.565
##  2   0  0  0  0  1     ?     0     -     -
##  8   0  0  1  1  1     ?     0     -     -
##  9   0  1  0  0  0     ?     0     -     -
## 10   0  1  0  0  1     ?     0     -     -
## 16   0  1  1  1  1     ?     0     -     -
## 18   1  0  0  0  1     ?     0     -     -
## 23   1  0  1  1  0     ?     0     -     -
## 27   1  1  0  1  0     0     0     -     -
## 29   1  1  1  0  0     0     0     -     -
## 31   1  1  1  1  0     0     0     -     -
```

Rerun the analysis of sufficiency producing the ENHANCED intermediate solution for ~Y with the following directional expectations: 0,0,0,1,0

```
sol_nyi_esa <- minimize(TT_ny_esa,
                        include = "?",
                        details = TRUE,
                        dir.exp = c(0,0,0,1,0))

sol_nyi_esa
```

```
##
## From C1P1:
##
## M1:    ~GG*~AH + ~GG*~HI + ~HE*~GG*~HW + ~HE*~AH*HI -> ~HL
##
##                 inclS   PRI   covS   covU
## ----------------------------------------
## 1      ~GG*~AH  0.905  0.870  0.676  0.026
## 2      ~GG*~HI  0.927  0.897  0.398  0.043
## 3  ~HE*~GG*~HW  0.942  0.922  0.674  0.018
## 4   ~HE*~AH*HI  0.913  0.881  0.541  0.067
## ----------------------------------------
##             M1  0.894  0.862  0.851
```

Contradictory easy counterfactuals

Check if we are making contradictory easy counterfactuals Put them in an object named CEC

```
CEC <- intersect(rownames(sol_yi$i.sol$C1P1$EC),
                 rownames(sol_nyi$i.sol$C1P1$EC))
CEC
```

```
## character(0)
```

We have none

Simultaneous subset relations

Now check if one or more rows were included into the minimization for both outcome Y and ~Y Use the intersect command, create a new object SSR

```
SSR <- intersect(rownames(TT_y$tt)[TT_y$tt$OUT==1],
                 rownames(TT_ny$tt)[TT_ny$tt$OUT==1])
SSR
```

```
## [1] "20"
```

Row 20 is included in both logical minimization processes, however, use the following commands to check the PRI value:

```
TT_y$tt[20,] # notice the low PRI value
```

```
##    HE GG AH HI HW OUT n              incl               PRI   cases
## 20  1  0  0  1  1   1 2 0.873479318734793 0.281105990783411 COL,THA
```

```
TT_ny$tt[20,] # PRI is much higher and much above 0.5
```

```
##    HE GG AH HI HW OUT n             incl               PRI   cases
## 20  1  0  0  1  1   1 2 0.94566098945661 0.691244239631335 COL,THA
```

We see that while for outcome HL, PRI is very low, for outcome ~HL, PRI is much better (0.69), so we keep it in the logical minimization.

Impossible remainders

The combination of four conditions never empirically occurs: $_{\text{H_EDU}}G_GOV$AFF_HEAL*~H_INCEQ, so let's assume that it is impossible. Avoid untenable assumptions on any logical remainder that contains the combination of these four conditions. Produce new ENHANCED intermediate solution for ~Y:

```
TT_ny_esa <- esa(TT_ny,
                 nec_cond = "~HE+~GG",
                 untenable_LR = "~HE*GG*~AH*~HI")
TT_ny_esa
```

```
##
##   OUT: output value
##     n: number of cases in configuration
##  incl: sufficiency inclusion score
##   PRI: proportional reduction in inconsistency
##
##      HE GG AH HI HW   OUT    n   incl  PRI
## 19   1  0  0  1  0     1     2   0.960 0.827
##  5   0  0  1  0  0     1     4   0.954 0.892
## 11   0  1  0  1  0     1     7   0.954 0.908
## 25   1  1  0  0  0     0     2   0.953 0.803
##  3   0  0  0  1  0     1     30  0.951 0.929
##  1   0  0  0  0  0     1     16  0.950 0.926
##  7   0  0  1  1  0     1     2   0.947 0.849
## 20   1  0  0  1  1     1     2   0.946 0.691
## 22   1  0  1  0  1     1     2   0.935 0.791
##  4   0  0  0  1  1     1     4   0.934 0.781
## 12   0  1  0  1  1     1     6   0.912 0.752
## 24   1  0  1  1  1     0     2   0.894 0.490
## 28   1  1  0  1  1     0     4   0.806 0.405
## 32   1  1  1  1  1     0     5   0.650 0.175
## 30   1  1  1  0  1     0     36  0.285 0.055
## 17   1  0  0  0  0     ?     1   0.969 0.890
## 21   1  0  1  0  0     ?     1   0.963 0.855
## 13   0  1  1  0  0     ?     1   0.950 0.752
```

```
## 15   0  1  1  1  0     ?     1   0.940 0.755
##  6   0  0  1  0  1     ?     1   0.927 0.772
## 26   1  1  0  0  1     0     1   0.910 0.611
## 14   0  1  1  0  1     ?     1   0.898 0.565
##  2   0  0  0  0  1     ?     0     -     -
##  8   0  0  1  1  1     ?     0     -     -
##  9   0  1  0  0  0     0     0     -     -
## 10   0  1  0  0  1     0     0     -     -
## 16   0  1  1  1  1     ?     0     -     -
## 18   1  0  0  0  1     ?     0     -     -
## 23   1  0  1  1  0     ?     0     -     -
## 27   1  1  0  1  0     0     0     -     -
## 29   1  1  1  0  0     0     0     -     -
## 31   1  1  1  1  0     0     0     -     -
```

Produce the enhanced intermediate solution:

```
sol_nyi_esa <- minimize(TT_ny_esa,
                        details = TRUE,
                        include = "?",
                        dir.exp = c(0,0,0,1,0))
sol_nyi_esa
```

```
##
## From C1P1:
##
## M1:    ~GG*~AH + ~GG*~HI + ~HE*~GG*~HW + ~HE*~AH*HI -> ~HL
##
##                 inclS   PRI   covS   covU
## ----------------------------------------
## 1      ~GG*~AH  0.905  0.870  0.676  0.026
## 2      ~GG*~HI  0.927  0.897  0.398  0.043
## 3  ~HE*~GG*~HW  0.942  0.922  0.674  0.018
## 4   ~HE*~AH*HI  0.913  0.881  0.541  0.067
## ----------------------------------------
##             M1  0.894  0.862  0.851
```

7. THEORY EVALUATION

Let us assume that according to our theory,
good governance (GG) and affluent health system (AH) or low income inequality (~HI) lead to high life expectancy (HL)

Intersect theory with the most parsimonious solution:

```
TH <- theory.evaluation(theory = "GG*AH+~HI",
                        empirics =  sol_yp,
                        outcome = "HL",
                        sol = 1)
TH
```

```
##
## CASES:
## **********************
##
## Covered Most Likely (T*S and Y > 0.5) :
## -------------------
##
## Boolean Expression: GG*~HE*~HI + GG*~HI*HW + AH*GG*HE*HW
##
## Cases in the intersection/Total number of cases: 37 / 131 = 28.24 %
## Cases in the intersection/Total number of cases Y > 0.5:  37 / 52 = 71.15 %
```

```
##
## Case Names:
## AUS AUT BRB BEL CAN HRV CYP CZE DNK EST FIN FRA DEU GRC HUN ISL IRL ISR ITA JPN KOR LUX M
## -------------------
##
## Covered Least Likely (~T*S and Y > 0.5) :
## -------------------
##
## Boolean Expression: ~AH*HE*HI*HW + ~GG*HE*HI*HW
##
## Cases in the intersection/Total number of cases: 4 / 131 = 3.05 %
## Cases in the intersection/Total number of cases Y > 0.5:  4 / 52 = 7.69 %
##
## Case Names:
## ARG CHL CRI TUR
## -------------------
##
## Uncovered Most Likely (T*~S and Y > 0.5) :
## -------------------
##
## Boolean Expression: ~GG*~HI + HE*~HI*~HW + AH*GG*~HE*HI + AH*GG*HE*~HW
##
## Cases in the intersection/Total number of cases:  3 / 131 = 2.29 %
## Cases in the intersection/Total number of cases Y > 0.5:  3 / 52 = 5.77 %
##
## Case Names:
## ALB TUN VNM
## -------------------
##
## Uncovered Least Likely (~T*~S and Y > 0.5) :
## -------------------
##
## Boolean Expression: ~AH*~HE*HI + ~AH*HI*~HW + ~GG*~HE*HI + ~GG*HI*~HW
##
## Cases in the intersection/Total number of cases:  8 / 131 = 6.11 %
## Cases in the intersection/Total number of cases Y > 0.5:  8 / 52 = 15.38 %
##
## Case Names:
## BIH CHN ECU IRN JAM MEX PAN PER
## -------------------
##
## Inconsistent Most Likely (T*S and Y < 0.5) :
## -------------------
##
## Boolean Expression: GG*~HE*~HI + GG*~HI*HW + AH*GG*HE*HW
##
## Cases in the intersection/Total number of cases:  0 / 131 = 0 %
## Cases in the intersection/Total number of cases Y < 0.5:  0 / 79 = 0 %
##
## Case Names:
## No cases in this intersection
## -------------------
##
## Inconsistent Least Likely (~T*S and Y < 0.5) :
## -------------------
##
## Boolean Expression: ~AH*HE*HI*HW + ~GG*HE*HI*HW
##
## Cases in the intersection/Total number of cases:  4 / 131 = 3.05 %
```

```
## Cases in the intersection/Total number of cases Y < 0.5:  4 / 79 = 5.06 %
##
## Case Names:
## COL LBN MYS THA
## --------------------
##
## Consistent Most Likely (T*~S and Y < 0.5) :
## --------------------
##
## Boolean Expression: ~GG*~HI + HE*~HI*~HW + AH*GG*~HE*HI + AH*GG*HE*~HW
##
## Cases in the intersection/Total number of cases:  25 / 131 = 19.08 %
## Cases in the intersection/Total number of cases Y < 0.5:  25 / 79 = 31.65 %
##
## Case Names:
## ARM AZE BDI KHM CMR EGY ETH GEO IND IDN JOR KAZ KGZ LAO LBR MLI MDA PAK RUS LKA TJK TZA T
## --------------------
##
## Consistent Least Likely (~T*~S and Y < 0.5) :
## --------------------
##
## Boolean Expression: ~AH*~HE*HI + ~AH*HI*~HW + ~GG*~HE*HI + ~GG*HI*~HW
##
## Cases in the intersection/Total number of cases:  43 / 131 = 32.82 %
## Cases in the intersection/Total number of cases Y < 0.5:  43 / 79 = 54.43 %
##
## Case Names:
## AGO BGD BLZ BEN BTN BOL BWA BFA CPV TCD CIV DOM SLV GAB GMB GHA GTM GIN GUY HND KEN MDG M
## --------------------
```

8. ROBUSTNESS

Sensitivity ranges:

Find the raw consistency and the frequency cut sensitivity ranges (for Y):

```
rob.inclrange(
  data = PAYF,
  step = 0.01,
  max.runs = 20,
  outcome  = "HL",
  conditions =  conds,
  incl.cut = 0.84,
  n.cut = 1,
  include = "?"
)
```

```
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## Raw Consistency T.:  Lower bound  0.81 Threshold  0.84 Upper bound  0.84
```

```
rob.ncutrange(
  data = PAYF,
  step = 1,
  max.runs = 20,
  outcome  = "HL",
  conditions =  conds,
```

```
  incl.cut = 0.84,
  n.cut = 1,
  include = "?"
)
```

```
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## [1] "Searching for thresholds, this takes me a while for now, sorry..."
## N.Cut:  Lower bound  1 Threshold  1 Upper bound  1
```

Load the raw data:

```
data("PAYR")
head(PAYR)
```

```
##       COUNTRY                 REGION LIFEX EDUC   GOV  HEAL INCEQ  WEAL
## ALB   Albania        European Region  77.8 3.85 -0.23 -0.24 17.52  9569
## AGO    Angola         African Region  52.4 2.01 -1.07 -0.75 43.06  5669
## ARG Argentina Region of the Americas  76.3 4.48 -0.30  0.16 31.52 18233
## ARM   Armenia        European Region  74.8 3.82 -0.26  0.17 12.74  7062
## AUS Australia Western Pacific Region  82.8 5.56  1.60  1.38 16.82 41576
## AUT   Austria        European Region  81.5 5.43  1.57  1.88 14.44 43459
```

Creating the test solutions:

Alter consistency to 0.8 and inclusion cutoff to 2. Create a new object TS1

```
TS1 <- minimize(data = PAYF,
                outcome  = "HL",
                conditions = conds,
                incl.cut = 0.8,
                n.cut = 2,
                include = "?",
                details = TRUE, show.cases = TRUE)
TS1
```

```
##
## M1: HE*HI + (HE*GG) -> HL
## M2: HE*HI + (GG*~HI) -> HL
##
##                                  --------------------
##            inclS   PRI   covS   covU   (M1)   (M2)
## ---------------------------------------------------
## 1  HE*HI  0.809  0.606  0.353  0.049  0.049  0.188
## ---------------------------------------------------
## 2   HE*GG  0.874  0.828  0.820  0.034  0.515
## 3  GG*~HI  0.841  0.790  0.659  0.013         0.494
## ---------------------------------------------------
##        M1  0.849  0.789  0.869
##        M2  0.820  0.748  0.847
##
##            cases
## ----------------
## 1   HE*HI  CHN,PHL; COL,THA; ARG,LBN; CHL,CRI,MYS,TUR; BRA,HRV,ISR,USA,URY
## ----------------
## 2   HE*GG  JOR,TUN; CHL,CRI,MYS,TUR; AUS,AUT,BRB,BEL,BGR,CAN,CYP,CZE,DNK,EST,FIN,FRA,DEU,
##            BRA,HRV,ISR,USA,URY
## 3  GG*~HI  JOR,TUN; AUS,AUT,BRB,BEL,BGR,CAN,CYP,CZE,DNK,EST,FIN,FRA,DEU,GRC,HUN,ISL,IRL,I
## ----------------
```

Alter calibration for the condition HW, using the condition WEAL in the raw dataset and putting thresholds at 4000, 25000, and 45000

```
PAYF2 <- PAYF
PAYF2$HW <- calibrate(PAYR$WEAL,
                      type="fuzzy",
                      thresholds = c(4000,25000,45000),
                      logistic = TRUE,
                      idm = 0.95)
```

Create object called TS2. This should be the most parsimonious solution using parameters from the very first truth table (sufficiency analysis for the presence of the outcome)

```
TS2 <- minimize(data = PAYF2,
                outcome  = "HL",
                conditions = conds,
                incl.cut = 0.84,
                n.cut = 1,
                include = "?",
                details = TRUE, show.cases = TRUE)

TS2
```

```
##
## M1: HE*GG*HI + HE*AH*HI + GG*AH*~HI -> HL
##
##               inclS   PRI   covS   covU
## ----------------------------------------
## 1   HE*GG*HI  0.865  0.715  0.304  0.080
## 2   HE*AH*HI  0.908  0.777  0.252  0.028
## 3  GG*AH*~HI  0.908  0.878  0.631  0.481
## ----------------------------------------
##           M1  0.885  0.837  0.813
##
##               cases
## ------------------
## 1   HE*GG*HI  CHL,CRI,MYS,TUR; BRA,HRV,URY; ISR,USA
## 2   HE*AH*HI  ARG,LBN; BRA,HRV,URY; ISR,USA
## 3  GG*AH*~HI  MNG,SRB; BRB,BGR,HUN,LVA,LTU,MNE,POL,ROM,SVK; AUS,AUT,BEL,CAN,CYP,CZE,DNK,E
## ------------------
```

Save the most parsimonious solution for the presence of the outcome as a new object IS:

```
IS <- sol_yp
```

Create the test set in a list:

```
TS <- list(TS1, TS2)
```

Calculate robustness fit parameters:

```
rob.fit(test_sol = TS,
        initial_sol = IS,
        outcome = "HL")
```

```
##                RF_cov RF_cons RF_SC_minTS RF_SC_maxTS
## Robustness_Fit   0.92   0.941       0.848       0.907
```

Identify types of robustness relevant cases and robustness case parameters:

```
rob.fit(test_sol = TS,
        initial_sol = IS,
        outcome = "HL")
```

```
##                RF_cov RF_cons RF_SC_minTS RF_SC_maxTS
## Robustness_Fit   0.92   0.941       0.848       0.907
```

9. SMMR Y

Print the typical cases for each focal conjunct in the second sufficient term of the intermediate solution

```
typ_foc <- smmr(sol_yi,
            outcome = "HL",
            match = FALSE,
            cases = 2,
            term = 2)
typ_foc
```

```
## Typical Cases - Focal Conjunct HE :
## ----------
##     FocalConj Outcome CompConj Term UniqCov Best MostTypFC Rank ConsFC
## TUR      0.57    0.59     0.70 0.57   FALSE 0.47     FALSE    1   TRUE
## CHL      0.90    0.96     0.83 0.83   FALSE 0.29     FALSE    2   TRUE
## ISR      0.98    0.99     0.62 0.62   FALSE 0.40     FALSE    2   TRUE
## HRV      0.78    0.85     0.65 0.65   FALSE 0.49     FALSE    2   TRUE
## CRI      0.88    0.94     0.61 0.61   FALSE 0.51     FALSE    2   TRUE
##     MostTypTerm
## TUR       FALSE
## CHL       FALSE
## ISR       FALSE
## HRV       FALSE
## CRI       FALSE
##
## Typical Cases - Focal Conjunct HI :
## ----------
##     FocalConj Outcome CompConj Term UniqCov Best MostTypFC Rank ConsFC
## USA      0.91    0.93     1.00 0.91   FALSE 0.13      TRUE    1   TRUE
## HRV      0.65    0.85     0.78 0.65   FALSE 0.75     FALSE    1   TRUE
## ISR      0.62    0.99     0.96 0.62   FALSE 1.12     FALSE    1   TRUE
## CHL      0.97    0.96     0.83 0.83   FALSE 0.19     FALSE    2  FALSE
## URY      0.80    0.75     0.74 0.74   FALSE 0.36     FALSE    2  FALSE
##     MostTypTerm
## USA        TRUE
## HRV       FALSE
## ISR       FALSE
## CHL       FALSE
## URY       FALSE
##
## Typical Cases - Focal Conjunct HW :
## ----------
##     FocalConj Outcome CompConj Term UniqCov Best MostTypFC Rank ConsFC
## URY      0.74    0.75     0.80 0.74   FALSE 0.28     FALSE    1   TRUE
## CHL      0.83    0.96     0.90 0.83   FALSE 0.43     FALSE    1   TRUE
## CRI      0.61    0.94     0.88 0.61   FALSE 1.05     FALSE    1   TRUE
## HRV      0.84    0.85     0.65 0.65   FALSE 0.37     FALSE    2   TRUE
## ISR      0.96    0.99     0.62 0.62   FALSE 0.44     FALSE    2   TRUE
##     MostTypTerm
## URY       FALSE
## CHL       FALSE
## CRI       FALSE
## HRV       FALSE
## ISR       FALSE
```

Show the typical - IIR cases for each term, using the intermediate solution:

```
typ_iir_term <- smmr(results = sol_yi,
                     outcome = "HL",
                     match = TRUE,
                     cases = 6)
typ_iir_term
```

```
## Term HE*GG*HW :
## ----------
##   Typical IIR UniqCov GlobUncov Best MostTyp ConsIIR
## 1     AUS AGO    TRUE      TRUE 0.02    TRUE    TRUE
## 2     CAN AGO    TRUE      TRUE 0.02    TRUE    TRUE
## 3     ISL AGO    TRUE      TRUE 0.02    TRUE    TRUE
## 4     NLD AGO    TRUE      TRUE 0.02    TRUE    TRUE
## 5     AUS BDI    TRUE      TRUE 0.02    TRUE    TRUE
##
## Term HE*HI*HW :
## ----------
##   Typical IIR UniqCov GlobUncov Best MostTyp ConsIIR
## 1     USA AGO    TRUE      TRUE 0.20    TRUE    TRUE
## 2     USA BDI    TRUE      TRUE 0.20    TRUE    TRUE
## 3     USA TCD    TRUE      TRUE 0.20    TRUE    TRUE
## 4     USA ETH    TRUE      TRUE 0.22    TRUE    TRUE
## 7     USA MRT    TRUE      TRUE 0.23    TRUE    TRUE
##
## Term ~HE*GG*AH*~HI :
## ----------
##    Typical IIR UniqCov GlobUncov Best MostTyp ConsIIR
## 1      SRB AGO    TRUE      TRUE 1.00    TRUE    TRUE
## 2      SRB BDI    TRUE      TRUE 1.00    TRUE    TRUE
## 4      SRB CIV    TRUE      TRUE 1.00    TRUE    TRUE
## 6      SRB NGA    TRUE      TRUE 1.00    TRUE    TRUE
## 11     SRB ZAF    TRUE      TRUE 1.03    TRUE    TRUE
```

10. SMMR ~Y

Display the deviant cases coverage, using the intermediate solution:

```
dcov <- smmr(results = sol_nyi,
             outcome = "HL",
             match = FALSE,
             cases = 4)
dcov
```

```
## Deviant Coverage Cases :
## ----------
##    Case SolMembership TT_HE TT_GG TT_AH TT_HI TT_HW TT_row_membership Outcome
## 7   MNG          0.47     0     1     1     0     0               0.53    0.94
## 3   GEO          0.36     0     1     1     1     0               0.64    0.58
## 4   LBN          0.39     1     0     1     1     1               0.61    0.53
## 8   MUS          0.29     1     1     0     0     1               0.59    0.56
## 9   MYS          0.17     1     1     0     1     1               0.82    0.52
## 5   LTU          0.06     1     1     1     0     1               0.76    0.66
## 10  ROM          0.28     1     1     1     0     1               0.72    0.52
## 1   BGR          0.25     1     1     1     0     1               0.61    0.57
## 6   LVA          0.09     1     1     1     0     1               0.58    0.56
## 2   BRA          0.38     1     1     1     1     1               0.53    0.52
##    Best MostDevCov ConsTT
## 7  0.47       TRUE   TRUE
## 3  0.36       TRUE  FALSE
```

```
## 4  0.39       TRUE  FALSE
## 8  0.41       TRUE  FALSE
## 9  0.18       TRUE  FALSE
## 5  0.24       TRUE  FALSE
## 10 0.28      FALSE  FALSE
## 1  0.39      FALSE  FALSE
## 6  0.42      FALSE  FALSE
## 2  0.47       TRUE  FALSE
```

Using the intermediate solution, show the best pairs of Deviant Coverage - IIR cases in each TT row:

```
dcov_iir <- smmr(results = sol_nyi,
                 outcome = "HL",
                 match = TRUE,
                 cases = 4)
dcov_iir
```

```
## Matching Deviant Coverage-IIR Cases :
## ----------
##    DevCov IIR TT_HE TT_GG TT_AH TT_HI TT_HW Best ConsTT_DCV
## 1     LBN ARG     1     0     1     1     1 1.58      FALSE
## 2     MYS CHL     1     1     0     1     1 0.90      FALSE
## 3     MYS CRI     1     1     0     1     1 1.32      FALSE
## 4     MYS TUR     1     1     0     1     1 1.75      FALSE
## 5     LTU JPN     1     1     1     0     1 0.82      FALSE
## 6     LTU AUS     1     1     1     0     1 0.83      FALSE
## 7     LTU ISL     1     1     1     0     1 0.83      FALSE
## 8     LTU NLD     1     1     1     0     1 0.83      FALSE
## 9     LTU ITA     1     1     1     0     1 0.83      FALSE
## 10    BRA ISR     1     1     1     1     1 1.43      FALSE
## 11    BRA USA     1     1     1     1     1 1.49      FALSE
## 12    BRA HRV     1     1     1     1     1 1.57      FALSE
## 13    BRA URY     1     1     1     1     1 1.67      FALSE
```

11. CLUSTER ~Y

We use the enhanced intermediate solution for the negated outcome

Perform cluster diagnostics for the enhanced intermediate solution with “REGION” as clusters and “COUNTRY” as units:

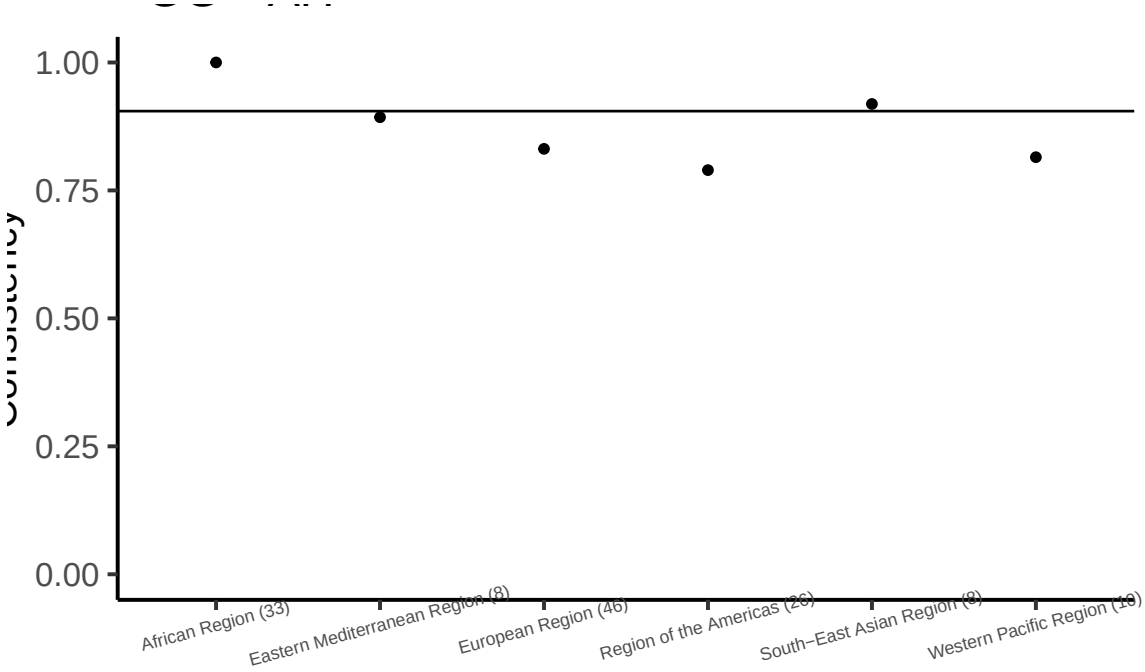
```
C_PAYF <- cluster(data = PAYF,
        result = sol_nyi_esa,
        outcome = "HL",
        unit_id = "COUNTRY",
        cluster_id = 'REGION',
        necessity = FALSE,
        wicons = FALSE)

C_PAYF
```

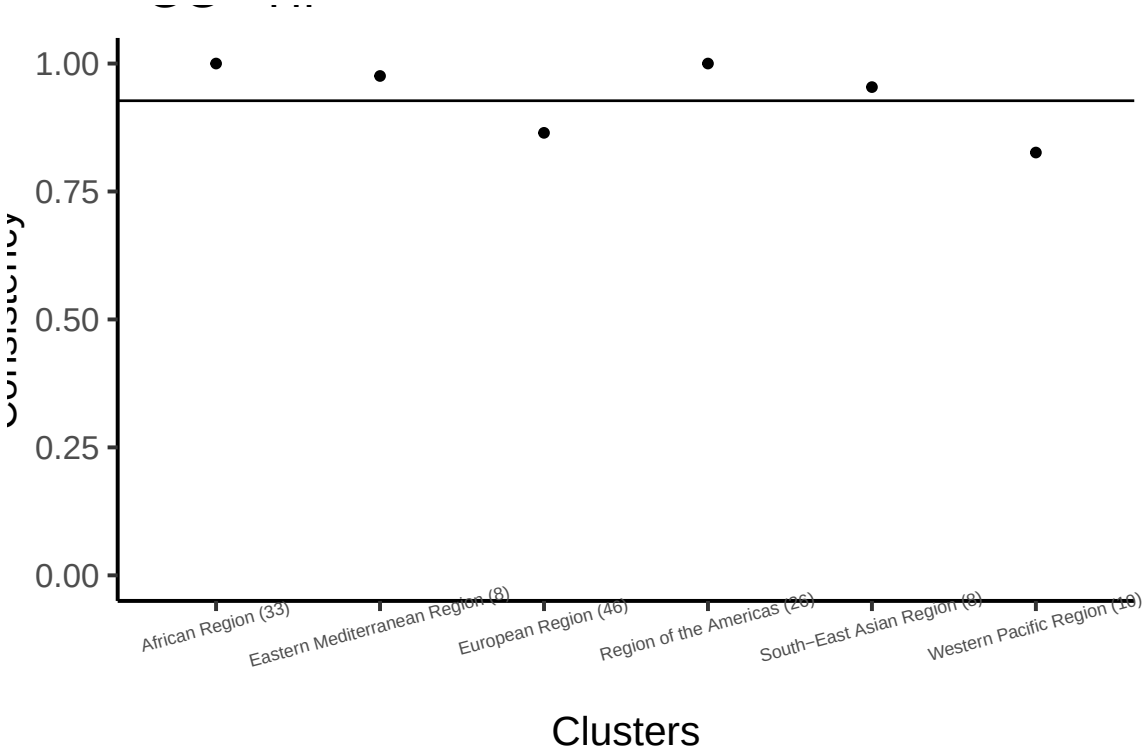
```
## Consistencies:
## ---------------
##                                              ~GG*~AH ~GG*~HI ~HE*~GG*~HW
## Pooled                                         0.905   0.927       0.942
## Between African Region (33)                    1.000   1.000       1.000
## Between Eastern Mediterranean Region (8)       0.893   0.976       0.977
## Between European Region (46)                   0.831   0.865       0.877
## Between Region of the Americas (26)            0.790   1.000       0.865
## Between South-East Asian Region (8)            0.919   0.954       0.954
```

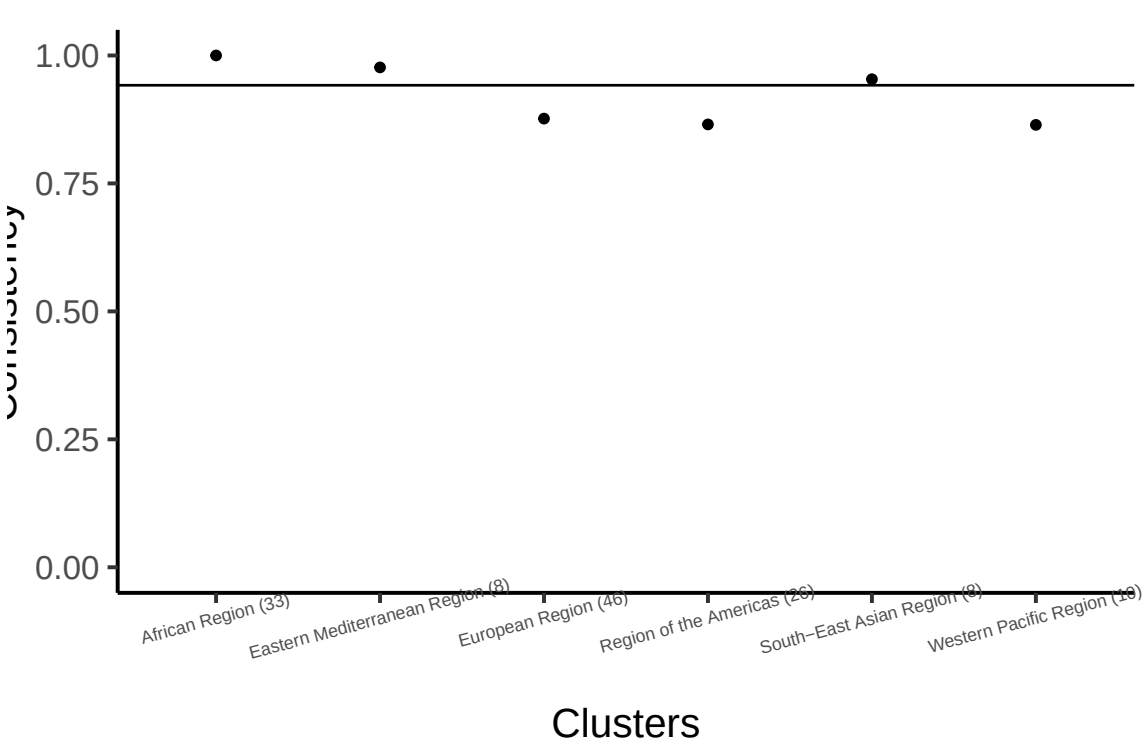
```
## Between Western Pacific Region (10)         0.815   0.826       0.864
##                                           ~HE*~AH*HI
## Pooled                                         0.913
## Between African Region (33)                    0.997
## Between Eastern Mediterranean Region (8)       0.950
## Between European Region (46)                   0.846
## Between Region of the Americas (26)            0.768
## Between South-East Asian Region (8)            1.000
## Between Western Pacific Region (10)            0.946
##
##
## Distances:
## ----------
##                         ~GG*~AH ~GG*~HI ~HE*~GG*~HW ~HE*~AH*HI
## From Between to Pooled    0.033   0.029       0.025      0.037
##
##
## Coverages:
## ----------
##                                           ~GG*~AH ~GG*~HI ~HE*~GG*~HW
## Pooled                                      0.676   0.398       0.674
## Between African Region (33)                 0.725   0.260       0.725
## Between Eastern Mediterranean Region (8)    0.838   0.734       0.688
## Between European Region (46)                0.313   0.751       0.480
## Between Region of the Americas (26)         0.784   0.110       0.693
## Between South-East Asian Region (8)         0.731   0.573       0.727
## Between Western Pacific Region (10)         0.754   0.524       0.703
##                                           ~HE*~AH*HI
## Pooled                                         0.541
## Between African Region (33)                    0.672
## Between Eastern Mediterranean Region (8)       0.312
## Between European Region (46)                   0.179
## Between Region of the Americas (26)            0.829
## Between South-East Asian Region (8)            0.410
## Between Western Pacific Region (10)            0.313
```

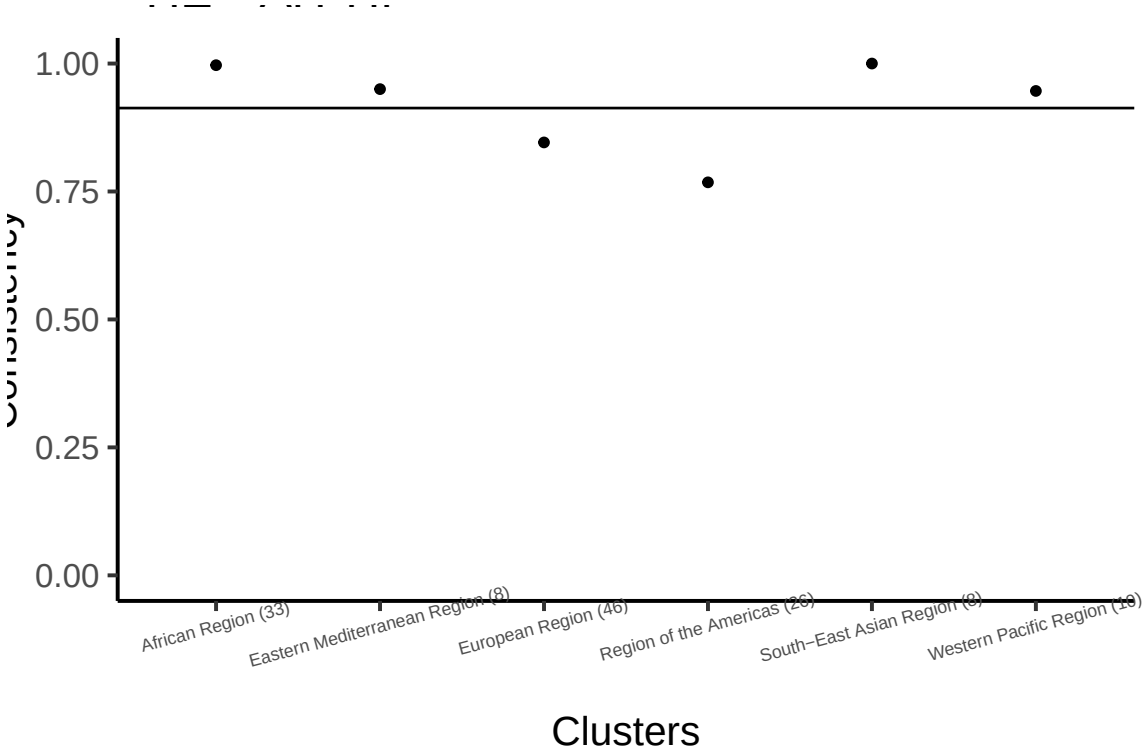
Plot between consistencies:

```
cluster.plot(C_PAYF,
             labs = TRUE,
             size = 7,
             angle = 15,
             wicons = FALSE)
```


1.00
0.75
0.50
0.25
0.00
African Region (33)
Eastern Mediterranean Region (8)
European Region (46)
Region of the Americas (26)
South−East Asian Region (8)
Western Pacific Region (19)
Clusters


1.00
0.75
0.50
0.25
0.00
African Region (33)
Eastern Mediterranean Region (8)
European Region (46)
Region of the Americas (26)
South−East Asian Region (8)
Western Pacific Region (19)
Clusters


1.00
0.75
0.50
0.25
0.00
African Region (33)
Eastern Mediterranean Region (8)
European Region (46)
Region of the Americas (26)
South−East Asian Region (8)
Western Pacific Region (19)
Clusters


1.00
0.75
0.50
0.25
0.00
African Region (33)
Eastern Mediterranean Region (8)
European Region (46)
Region of the Americas (26)
South−East Asian Region (8)
Western Pacific Region (19)
Clusters