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Black-Litterman Model

November 15, 2011
By systematicinvestor

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(This article was first published on **Systematic Investor » R**, and kindly contributed to R-bloggers)

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The Black-Litterman Model was created by Fisher Black and Robert Litterman in 1992 to resolve shortcomings of traditional Markovitz mean-variance asset allocation model. It addresses following two items:

- Lack of diversification of portfolios on the mean-variance efficient frontier.
- Instability of portfolios on the mean-variance efficient frontier: small changes in the input assumptions often lead to very different efficient portfolios.

I recommend a very good non-technical introduction to The Black-Litterman Model, An Introduction for the Practitioner by T. Idzorek (2009).

I will take the country allocation example presented in The Intuition Behind Black-Litterman Model Portfolios by G. He, R. Litterman (1999) paper and update it using current market data.

First, I need market capitalization data for each country to compute equilibrium portfolio. I found following two sources of capitalization data:

- World Development Indicators database at the World Databank. First select countries, for series type in "capitalization", and last choose years.
- World Federation of Exchanges.

I will use market capitalization data from World Databank.

```
# load Systematic Investor Toolbox
setInternet2(TRUE)
source(gzcon(url('https://github.com/systemat

    #---------------------------------------
    # Visualize Market Capitalization History
    #---------------------------------------

    hist.caps = aa.test.hist.capitalization()
    hist.caps.weight = hist.caps/rowSums(hist

    # Plot Transition of Market Cap Weights i
    plot.transition.map(hist.caps.weight, ind

    # Plot History for each Country's Market
    layout( matrix(1:9, nrow = 3, byrow=T) )
    col = plota.colors(ncol(hist.caps))
    for(i in 1:ncol(hist.caps)) {
        plota(hist.caps[,i], type='l', lwd=5,
    }
```

There is a major shift in weights between Japan and USA from 1988 to 2010. In 1988 Japan represented 47% and

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shift was driven by inflow of capital to USA, the Japaneses capitalization was pretty stable in time, as can be observed from time series plot for each country.

Second, I need historical prices series for each country to compute covariance matrix. I will use historical data from Yahoo Fiance:

Australia	EWA
Canada	EWC
France	EWQ
Germany	EWG
Japan	EWJ
U.K.	EWU
USA	SPY

The first step of the Black-Litterman model is to find implied equilibrium returns using reverse optimization.

$$\Pi = \delta \Sigma w_{eq}$$

where Π are equilibrium returns, δ is risk aversion, Σ is covariance matrix, and w_{eq} are market capitalization weights. The risk aversion parameter can be estimated from historical data by dividing the excess market portfolio return by its variance.

```
# Use reverse optimization to compute the vec
bl.compute.eqret <- function
(
    risk.aversion,  # Risk Aversion
    cov,        # Covariance matrix
    cap.weight,     # Market Capitalization W
    risk.free = 0   # Rsik Free Interest Rate
)
{
    return( risk.aversion * cov %*% cap.weigh
}

    #---------------------------------------
    # Compute Risk Aversion, prepare Black-Li
    #---------------------------------------
    ia = aa.test.create.ia.country()

    # compute Risk Aversion
    risk.aversion = bl.compute.risk.aversion(

    # the latest market capitalization weight
    cap.weight = last(hist.caps.weight)

    # create Black-Litterman input assumption
    ia.bl = ia
    ia.bl$expected.return = bl.compute.eqret(

    # Plot market capitalization weights and
    layout( matrix(c(1,1,2,3), nrow=2, byrow=
    pie(coredata(cap.weight), paste(colnames(
        main = paste('Country Market Capitali
        , col=plota.colors(ia$n))

    plot.ia(ia.bl, T)
```

Next, let' s compare the efficient frontier created using historical input assumptions and Black-Litterman input assumptions

```
#---------------------------------------
# Create Efficient Frontier(s)
#---------------------------------------
n = ia$n

# -1 <= x.i <= 1
constraints = new.constraints(n, lb = 0, ub =

# SUM x.i = 1
constraints = add.constraints(rep(1, n), 1, t
```

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```
ef.risk.bl = portopt(ia.bl, constraints, 50,

# Plot multiple Efficient Frontiers and Trans
layout( matrix(1:4, nrow = 2) )
plot.ef(ia, list(ef.risk), portfolio.risk, T,
plot.ef(ia.bl, list(ef.risk.bl), portfolio.ri
```

Comparing the transition maps, the Black-Litterman efficient portfolios are well diversified. Efficient portfolios have allocation to all asset classes at various risk levels. By its construction, the Black-Litterman model is well suited to address the diversification problems.

The Black-Litterman model also introduces a mechanism to incorporate investor' s views into the input assumptions in such a way that small changes in the input assumptions will NOT lead to very different efficient portfolios. The Black-Litterman model adjusts expected returns and covariance:

Formula does not parse

where P is Views pick matrix, and Q Views mean vector. The Black-Litterman model assumes that views are $N \sim (Q, P)$.

```
bl.compute.posterior <- function
(
    mu,          # Equilibrium returns
    cov,         # Covariance matrix
    pmat=NULL,   # Views pick matrix
    qmat=NULL,   # Views mean vector
    tau=0.025    # Measure of uncertainty of t
)
{
    out = list()
    omega = diag(c(1,diag(tau * pmat %*% cov

    temp = solve(solve(tau * cov) + t(pmat) %
    out$cov = cov + temp

    out$expected.return = temp %*% (solve(tau
    return(out)
}

    #---------------------------------------
    # Create Views
    #---------------------------------------
    temp = matrix(rep(0, n), nrow = 1)
        colnames(temp) = ia$symbols

    # Relative View
    # Japan will outperform UK by 2%
    temp[,'Japan'] = 1
    temp[,'UK'] = -1

    pmat = temp
    qmat = c(0.02)

    # Absolute View
    # Australia's expected return is 12%
    temp[] = 0
    temp[,'Australia'] = 1

    pmat = rbind(pmat, temp)
    qmat = c(qmat, 0.12)

    # compute posterior distribution paramete
    post = bl.compute.posterior(ia.bl$expecte

    # create Black-Litterman input assumption
    ia.bl.view = ia.bl
        ia.bl.view$expected.return = post$exp
        ia.bl.view$cov = post$cov
        ia.bl.view$risk = sqrt(diag(ia.bl.vie

    # create efficient frontier(s)
    ef.risk.bl.view = portopt(ia.bl.view, con

    # Plot multiple Efficient Frontiers and T
    layout( matrix(1:4, nrow = 2) )
    plot.ef(ia.bl, list(ef.risk.bl), portfoli
```

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Comparing the transition maps, the Black-Litterman + Views efficient portfolios have more allocation to Japan and Australia, as expected. The portfolios are well diversified and are not drastically different from the Black-Litterman efficient portfolios.

The Black-Litterman model provides an elegant way to resolve shortcomings of traditional Markovitz mean-variance asset allocation model based on historical input assumptions. It addresses following two items:

- Lack of diversification of portfolios on the mean-variance efficient frontier. The Black-Litterman model uses equilibrium returns implied from the current market capitalization weighs to construct well diversified portfolios.
- Instability of portfolios on the mean-variance efficient frontier. The Black-Litterman model introduces a mechanism to incorporate investor' s views into the input assumptions in such a way that small changes in the input assumptions will NOT lead to very different efficient portfolios.

I highly recommend exploring and reading following articles and websites for better understanding of the Black-Litterman model:

- The Intuition Behind Black-Litterman Model Portfolios by G. He, R. Litterman (1999)
- AllocationADVISOR and The Black-Litterman Model by T. Idzorek (2004)
- A STEP-BY-STEP GUIDE TO THE BLACK-LITTERMAN MODEL by T. Idzorek (2005)
- The Intuition Behind Black-Litterman Model Portfolios by G. He, R. Litterman (1999)
- A STEP-BY-STEP GUIDE TO THE BLACK-LITTERMAN MODEL by T. IDZOREK (2002)
- The Black-Litterman Model and Alternative Investments by M. Odo
- Incorporating Trading Strategies in the Black-Litterman Framework by F. FABOZZI, S. FOCARDI, P. KOLM (2006)
- Jay Walters published two papers on the The Black-Litterman Model: "The Black-Litterman Model In Detail" and "The Factor Tau in the Black-Litterman Model"
- Jay Walters also gathered a collection of Implementations of the Black-Litterman Model at his site.
- Beyond Black-Litterman in Practice: A Five-Step Recipe to Input Views on Non-Normal Markets by A. Meucci (2005) accompanied by Matlab code.
- Fully Flexible Views: Theory and Practice by A. Meucci (2008) accompanied by Matlab code.

To view the complete source code for this example, please have a look at the aa.black.litterman.test() function in aa.test.r at github.

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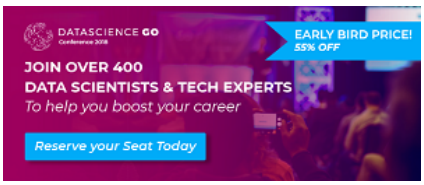

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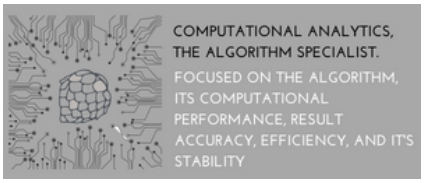

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