



## SAS<sup>®</sup> Econometrics 8.2: HMM Procedure

### Using Hidden Markov Models for Portfolio Selection

#### Overview

The HMM procedure supports hidden Markov models, which have been widely applied in economics, finance, science, and engineering. Hidden Markov models have many well-known aliases, such as general state space models, regime-switching models, Markov-switching models, and Markov regime-switching models. This procedure supports Gaussian hidden Markov models.

#### Model Details

Economic cycles inevitably influence the behavior of financial markets. These oscillations affect the general mood of investors, which in turn determines the nature of the market: “bull” or “bear.” A bullish market is characterized by an overall sense of optimism, and a bearish market is identified with a general sense of pessimism. Researchers have proposed several approaches to investigate the nature of these oscillations. Hidden Markov models represent a simple and useful tool to implement this theory. These models become particularly useful when the focus is on forecasting rather than trying to interpret the reasons for the swings in the economic time series.

To make the optimal portfolio selections, the analyst needs to do the following:

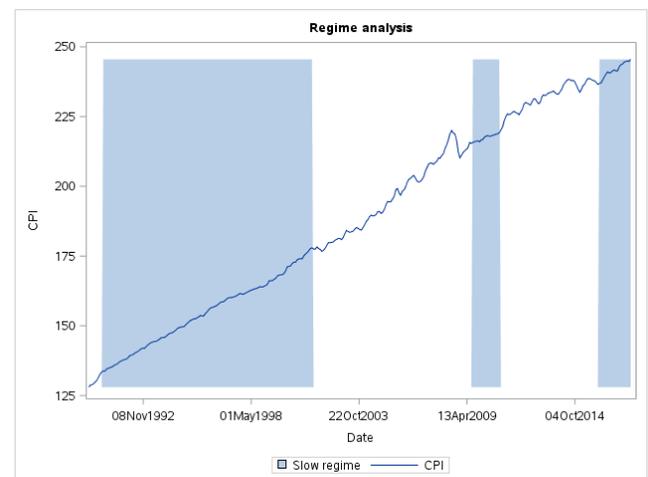
- Assess the investor's risk tolerance.
- Predict the behavior of the financial markets.
- Create a portfolio conditionally on the future behavior of the financial markets and the investor's risk tolerance.

Although the first assessment is highly subjective, the remaining two tasks can be done using analytical tools. Predicting the behavior of financial markets is both extremely interesting and quite challenging. This example emphasizes the relation between the macroeconomic cycle theory and the overall behavior of the financial markets.

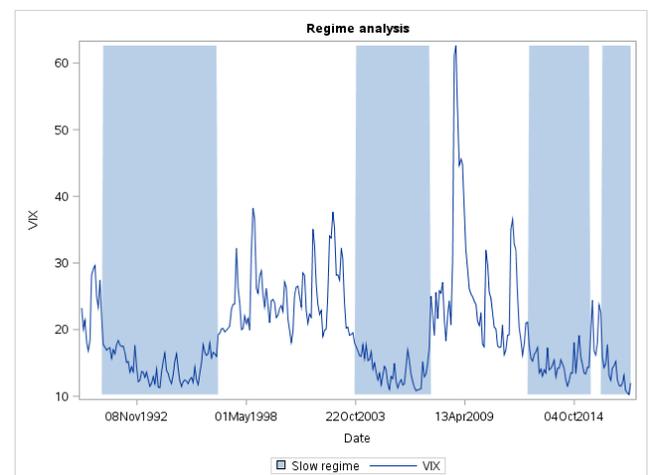
```
proc hmm data=mylib.data;
id time=date;
model CPI_c / type=Gaussian nstate=2 method=map;
prior tpm ~ dir(J(2,2,1)),
      musigma ~ niw(J(2,1,0),J(2,1,1),J(2,1,0.00001),
                  J(2,1,5));
learn out=mylib.est;
      decode out=mylib.decode;
run;
```

The HMM procedure produces all the elements that you need in order to identify the cycles in the macroeconomic variable of interest.

The first plot shows the identified regimes for the consumer price index (CPI).



The second plot shows the identified regimes for the volatility of S&P 500 index options.



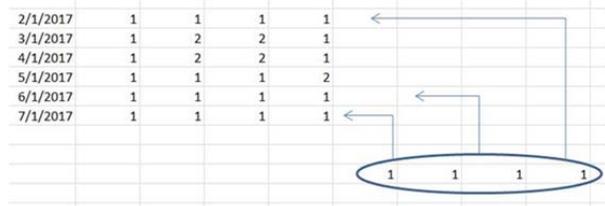
The analysis is further extended to industrial production and to the S&P 500 index.

## Forecasting the Cycles

After you estimate the model to identify the cycles, you can use the same model to forecast the future:

```
proc hmm data=mylib.data;
  id time=date;
  model CPI_c / type=Gaussian nstate=2 method=map;
  prior tpm ~ dir(J(2,2,1)),
        musigma ~ niw(J(2,1,0),J(2,1,1),J(2,1,0.00001),
                    J(2,1,5));
  forecast out=mylib.forecast lead=1;
run;
```

The set of forecasted states provides a unique signature that you can use to identify macroeconomic conditions that are similar to the forecasts.



To identify the stocks to be included in the portfolio, you can study their behavior during the months that match the forecasted signature. The following table provides some basic statistics about the stock returns of three companies: IBM, Oracle, and CVS.

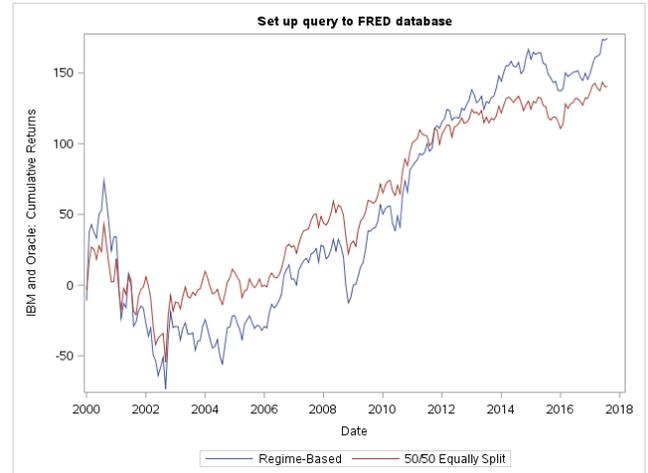
Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
ibm_c	331	0.98517	7.70439	326.08973	-24.85826	35.37992
orcl_c	331	2.22053	12.85477	734.99666	-44.08788	65.25345
cvs_c	331	1.02547	7.30151	339.43090	-29.69039	27.86408

The following table provides the correlation matrix.

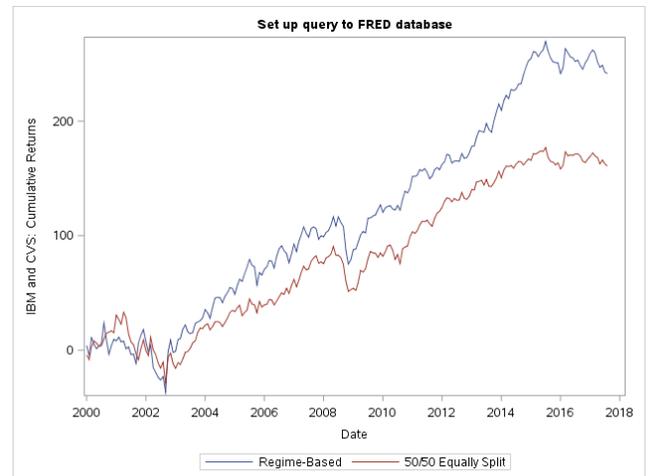
Pearson Correlation Coefficients, N = 331 Prob >  r  under H0: Rho=0			
	ibm_c	orcl_c	cvs_c
ibm_c	1.00000	0.28037 <.0001	0.17892 0.0011
orcl_c	0.28037 <.0001	1.00000	0.16742 0.0022
cvs_c	0.17892 0.0011	0.16742 0.0022	1.00000

By iterating the previous analysis starting from January 1, 2000, you can study the hypothetical behavior of a portfolio that allocates resources dynamically based on the fore-

casted states. For comparison, a portfolio is included that statically allocates 50% of the resources to each of the two stocks. In the following plot, notice that a portfolio characterized by highly correlated stocks (IBM and Oracle) does not achieve interesting results.



The following plot analyzes a portfolio characterized by mildly correlated stocks (IBM and CVS). It appears that considering stocks that are mildly correlated might favor the portfolio that allocates resources dynamically.



## System Requirements

Estimation as demonstrated in these examples has these system requirements:

- Base SAS® 9.4 or later
- SAS Econometrics 8.2

**Note:** This analysis is based on N. Nguyen and D. Nguyen, "Hidden Markov Model for Stock Selection," *Risks* 3 (2015): 455–473. Revisited by Christian Macaro.