FORECASTING PERFORMANCE OF MARKOV-SWITCHING GARCH MODELS: A LARGE-SCALE EMPIRICAL STUDY

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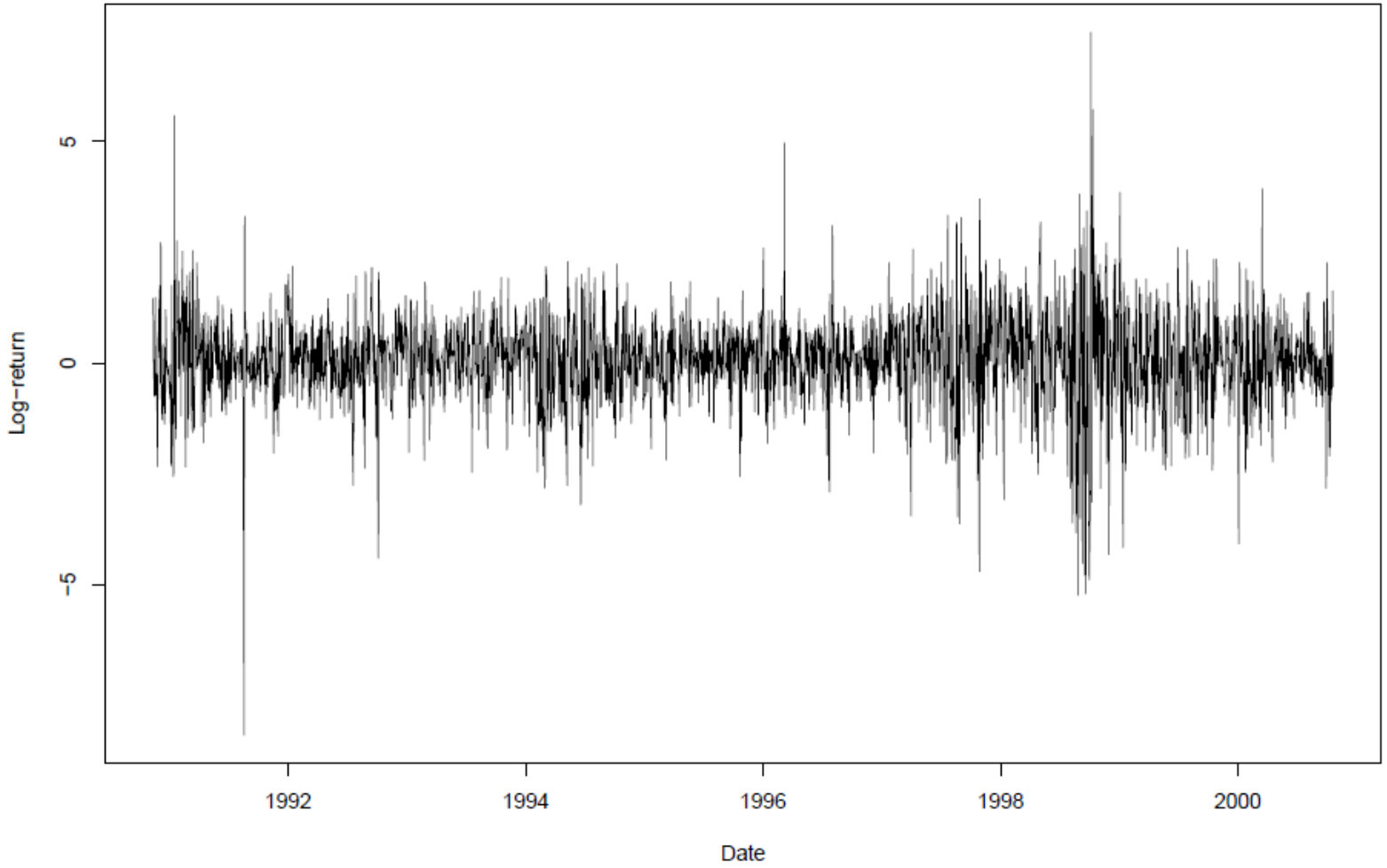
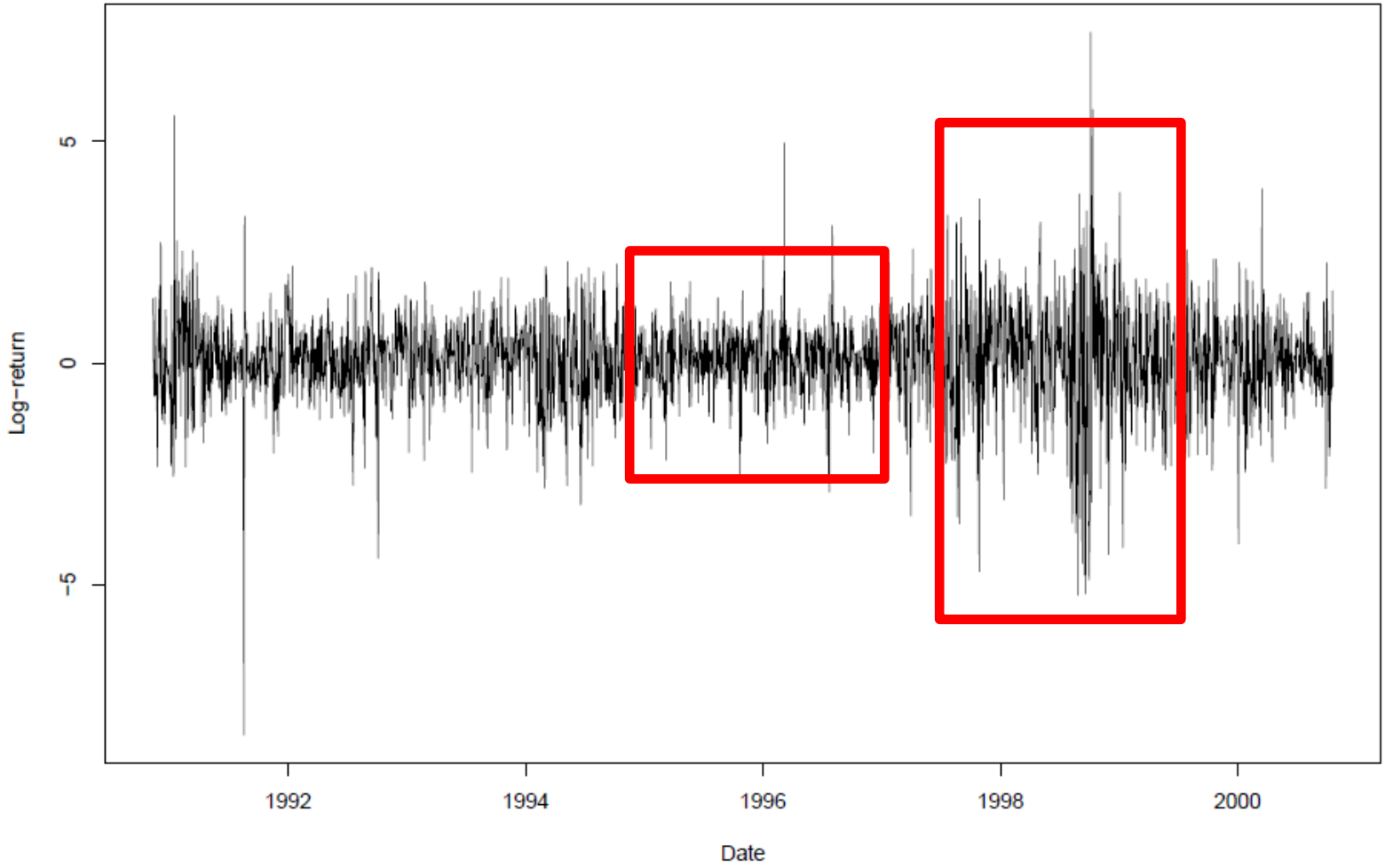
MOTIVATION – BACKGROUND

– Modeling the **volatility dynamics** of financial markets **is key**.



MOTIVATION – BACKGROUND

– *E.g.*, we need to account for **volatility clustering**.



MOTIVATION – GARCH

– GARCH-type models (Bollerslev, 1986):

$$y_t | I_{t-1} \sim D(0, h_t, \boldsymbol{\xi})$$

Conditional variance h_t:

$$h_t \equiv \omega + \alpha y_{t-1}^2 + \beta h_{t-1}$$

Shape parameters in $\boldsymbol{\xi}$.

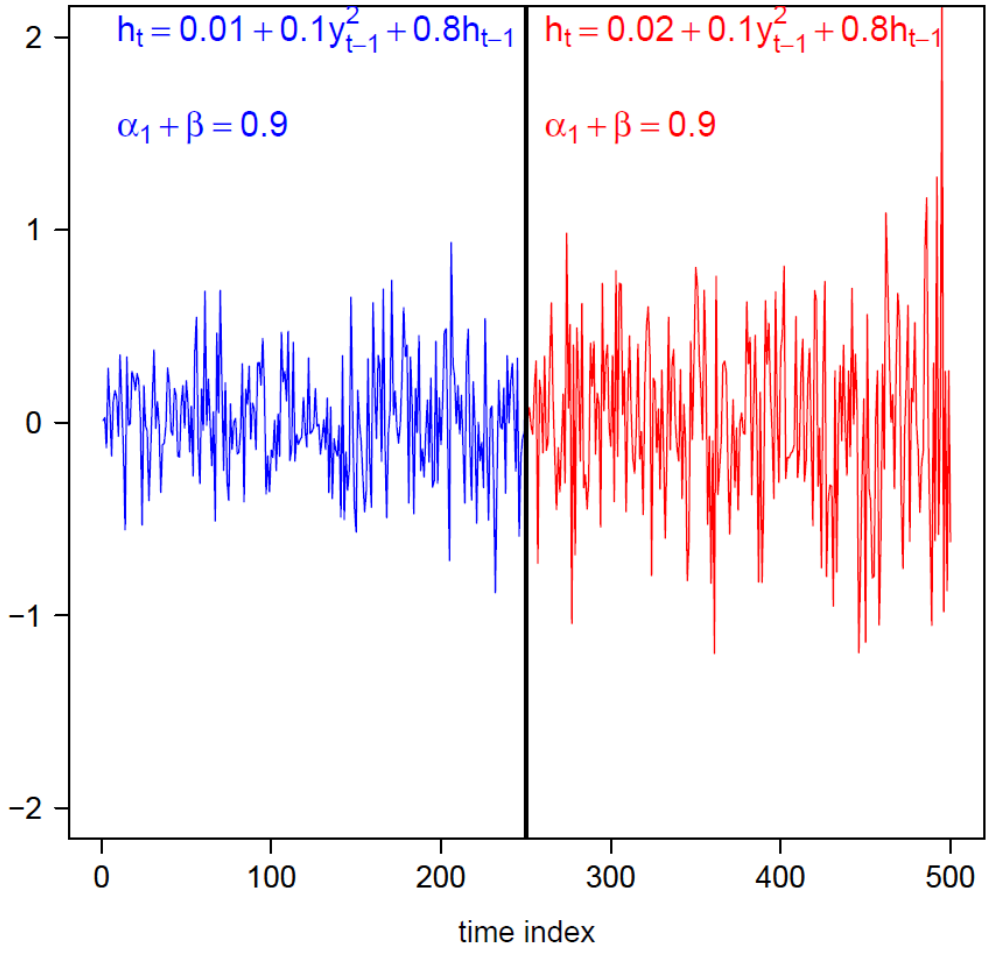
Nice but:

– Estimates of **GARCH** models can be **biased** by **structural breaks** in the volatility dynamics.

Implies poor risk predictions.

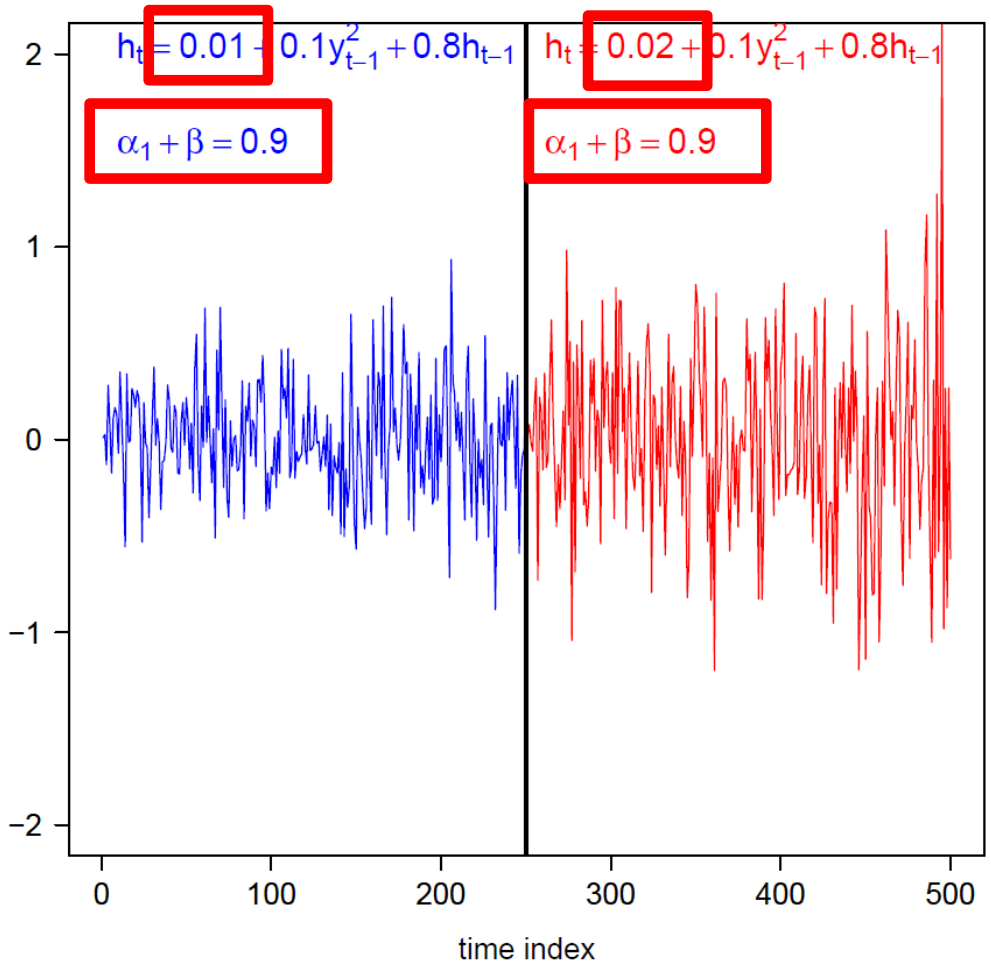
MOTIVATION – BREAK

– Simulation in which we have a break in the GARCH parameters.



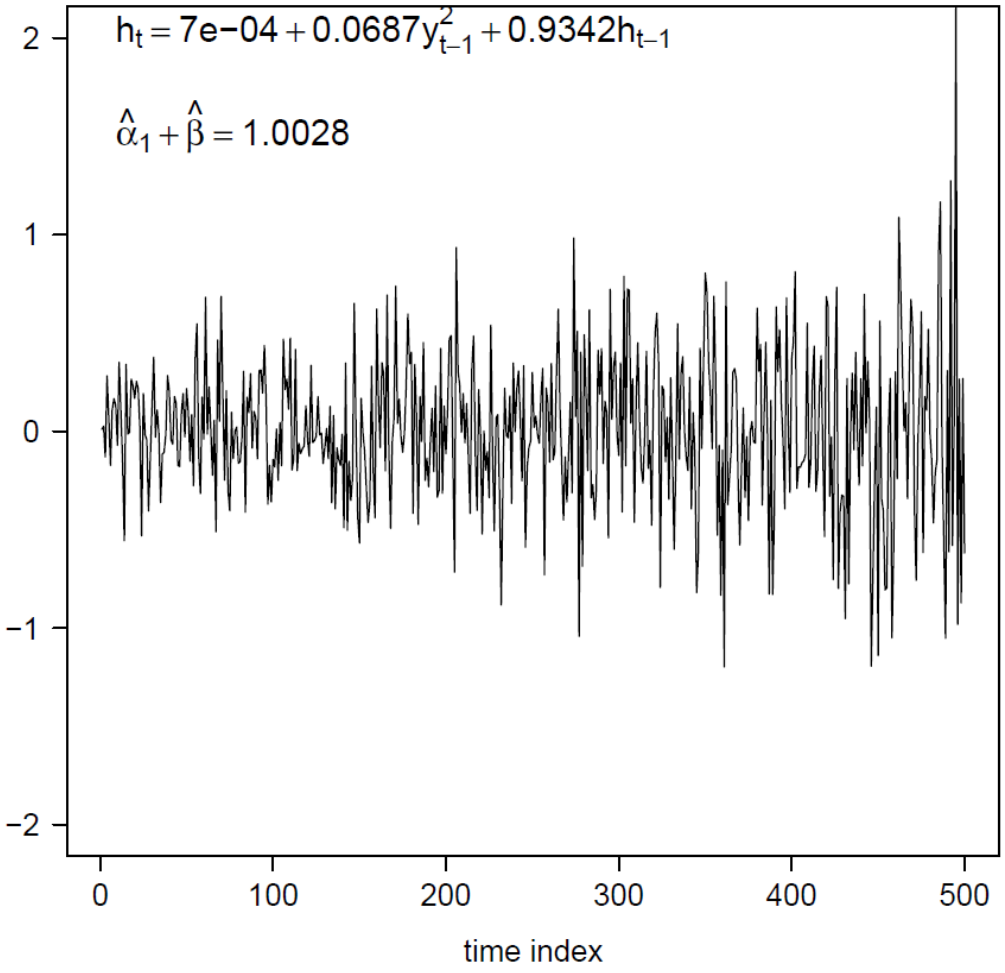
MOTIVATION – BREAK

– Covariance stationary but unconditional variance increases.



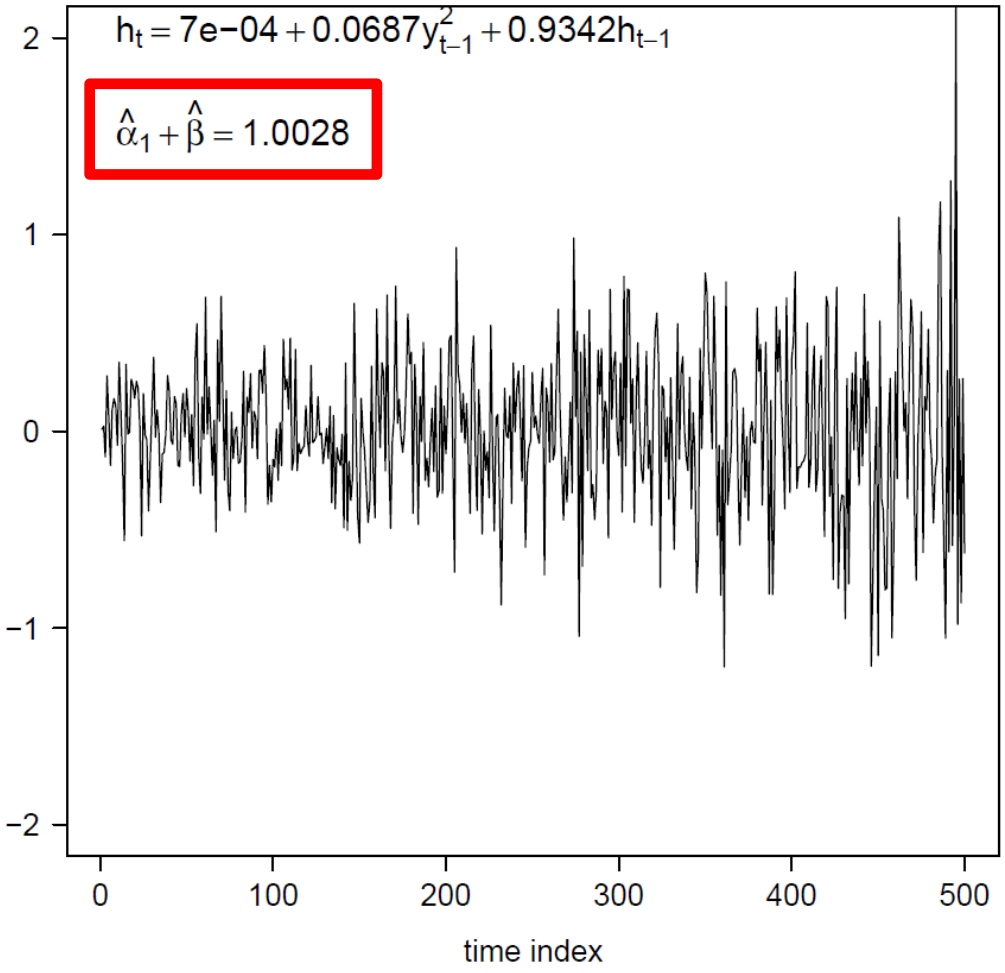
MOTIVATION – BREAK

– Estimation assuming a single-regime (set of parameters).



MOTIVATION – BREAK

– Integrated GARCH is obtained.



A SOLUTION

– Markov-switching GARCH (**MSGARCH**) models.

$$y_t|(s_t = k, I_{t-1}) \sim D(0, h_{k,t}, \boldsymbol{\xi}_k)$$

Conditional on state $s_t = k$, variance $h_{k,t}$ and distribution parameters $\boldsymbol{\xi}_k$.

– K regimes with specific GARCH-type parameters (Haas et al. 2004):

$$h_{1,t} \equiv \omega_1 + \alpha_1 y_{t-1}^2 + \beta_1 h_{1,t-1}$$
$$\vdots$$
$$h_{K,t} \equiv \omega_K + \alpha_K y_{t-1}^2 + \beta_K h_{K,t-1}$$

– **Discrete-state** variable s_t evolves according to a first-order **Markov chain** with transition matrix $\boldsymbol{P}$.

MSGARCH

- Approach by Haas et al. (2004) has several attractive features:
  - Computationally **tractable**.
  - **Interpretation** of the parameters.

    Persistence and past shocks can be different across regimes.

- Several papers (*e.g.*, Marcucci 2005, Ardia 2008, Bauwens et al. 2010) have reported **better** forecasting **performance** of **MSGARCH** compared to single-regime GARCH.

- Still, MSGARCH is more *complicated* and *difficult* to estimate.

  We use the R **package MSGARCH** available on CRAN.

RESEARCH QUESTIONS

1. Are MSGARCH models **relevant in practice**?
   - Comparison with GARCH-type models.
   - Large scale study (hundred of stocks, several indices, etc.).

2. Should we **integrate parameter uncertainty** in risk forecasts?
   - ML vs. MCMC (Bayesian).

     Predictive distribution of returns.

OUR STUDY – DATA & MODELS

- Data (univariate):
  - S&P 500 stocks (400).
  - Major stock indices (11).
  - Currencies (8).

- Models:
  - Single-regime & 2-state MSGARCH models.
  - GARCH & GJR (asymmetric GARCH).
  - Normal & Student (and skew versions).

OUR STUDY – ESTIMATION & FORECASTING

- Estimation:
  - 1,500 ITS rolling windows of daily returns.
  - ML & MCMC estimation.

- Forecasting:
  - 2,000 OTS returns.
  - **One-day ahead** performance of **tail forecasts**.

(1) VALUE-AT-RISK TEST – SETUP

- We **backtest** the VaR using DQ test (Engle & Manganelli 2004).
- We report the percentage of rejections (at the 5% level) per asset class (we correct for false positive following Storey 2002 for stocks).

  Low percentages are preferred.
- **Test if MS outperforms SR**.
- **Test if MCMC outperforms ML**.
- Get similar results with UC and CC tests (Christoffersen 1998).

(1) VALUE-AT-RISK TEST – RESULTS

	Stocks			
	MCMC		ML	
Model	MS	SR	MS	SR
Panel C: DQ 1%–VaR				
GARCH $\mathcal{N}$	29.50	58.75	30.25	62.25
GARCH sk$\mathcal{N}$	21.50	53.25	28.25	57.00
GARCH $\mathcal{S}$	28.25*	30.00	35.00	37.00
GARCH sk$\mathcal{S}$	24.25*	26.75	31.25	32.00
GJR $\mathcal{N}$	14.75	44.00	14.75	47.75
GJR sk$\mathcal{N}$	10.25	33.75	11.50	41.25
GJR $\mathcal{S}$	9.75	13.00	13.75	19.25
GJR sk$\mathcal{S}$	11.75	12.00	12.25	17.75
Panel D: DQ 5%–VaR				
GARCH $\mathcal{N}$	14.50*	23.75	17.75	29.50
GARCH sk$\mathcal{N}$	7.50*	27.25	9.75	29.50
GARCH $\mathcal{S}$	5.75*	10.00	13.75	21.75
GARCH sk$\mathcal{S}$	3.00*	9.75	9.25	12.75
GJR $\mathcal{N}$	1.00*	12.75	3.50	16.50
GJR sk$\mathcal{N}$	1.00*	11.75	3.50	15.00
GJR $\mathcal{S}$	0.75	0.00	1.75	3.50
GJR sk$\mathcal{S}$	0.50	0.25	0.25	2.50

Table with the frequencies of rejections (at the 5%) with false positive correction.

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GJR sk$\mathcal{S}$	0.50	0.25	0.25	2.50

Table with the frequencies of rejections (at the 5%) with false positive correction.

- Focus on **stocks** first.
- VaR 1% and 5% levels.

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Research questions:

– **MS** (significantly) **better** for MCMC

Note:

Light gray indicates significant outperformance between MS and SR.

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Research questions:

– **MS** (significantly) **better** for MCMC and ML.

Note:

Light gray indicates significant outperformance between MS and SR.

(1) VALUE-AT-RISK TEST – RESULTS

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	MCMC		ML	
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Research questions:

- **MS** (significantly) **better**.
- **MCMC** (significantly) **better**.

Note:

Star indicates significant outperformance between MCMC and ML.

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Research questions:

– **MS** (significantly) **better**.

– **MCMC** (significantly) **better**.

Note:

– GJR is preferred.

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Research questions:

- **MS** (significantly) **better**.
- **MCMC** (significantly) **better**.

Note:

- GJR is preferred.
- Student is preferred.

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Research questions:

- **MS** (significantly) **better**.
- **MCMC** (significantly) **better**.

Note:

- GJR is preferred.
- Student is preferred.
- Skewness is preferred.

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Research questions:

- **MS** (significantly) **better**.
- **MCMC** (significantly) **better**.

Note:

- GJR is preferred.
- Student is preferred.
- Skewness is preferred.
- SR skewed Student performs remarkably well.

(1) VALUE-AT-RISK TEST – RESULTS

Stock indices				Currencies			
MCMC		ML		MCMC		ML	
MS	SR	MS	SR	MS	SR	MS	SR
81.82	100.00	63.64	90.91	25.00	37.50	25.00	37.50
36.36*	72.73	54.55	81.82	0.00*	37.50	12.50	37.50
63.64	72.73	72.73	63.64	37.50	25.00	12.50	12.50
45.45	45.45	45.45	45.45	25.00	12.50	12.50	12.50
63.64	90.91	63.64	90.91	25.00	37.50	12.50	37.50
9.09	54.55	0.00	54.55	25.00	25.00	12.50	25.00
36.36	27.27	54.55	54.55	25.00	25.00	25.00	25.00
9.09	9.09	0.00	0.00	12.50	25.00	12.50	25.00
36.36	54.55	18.18	36.36	0.00	12.50	0.00	0.00
9.09	9.09	9.09	9.09	0.00	0.00	0.00	0.00
36.36	54.55	54.55	54.55	0.00	25.00	12.50	0.00
0.00	18.18	18.18	9.09	0.00	0.00	0.00	0.00
0.00	9.09	9.09	9.09	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	9.09	9.09	36.36	37.50	25.00	0.00	12.50
0.00	9.09	0.00	9.09	0.00	0.00	0.00	0.00

Research questions:

– **Less clear** (significant) conclusion for **stock indices** and **currencies**.

(2) LEFT-TAIL TEST – SETUP

- We perform a **pairwise comparison** of the forecasting performance of the **left tail** returns distribution for MS vs. SR.

- For each model and asset in a universe, we compute the Diebold-Mariano (1995) statistics of the weighted **CRPS** (and QL) differentials between MS and SR models (Gneiting & Ranjan 2011).

- We then report the average value:

  Negative value indicates outperformance of MS.

  Light (dark) gray reports significant outperformance (at the 1% level) of MS (SR).

- Results are reported for MCMC only.

(2) LEFT-TAIL TEST – RESULTS

	Stocks		
	QL 1%	QL 5%	wCRPS
GARCH $\mathcal{N}$	1.01	-3.51	-9.49
GARCH sk$\mathcal{N}$	0.49	-4.21	-9.75
GARCH $\mathcal{S}$	-2.94	-2.95	-2.70
GARCH sk$\mathcal{S}$	1.38	-3.22	-2.00
GJR $\mathcal{N}$	0.64	-4.99	-9.86
GJR sk$\mathcal{N}$	1.10	-5.25	-10.08
GJR $\mathcal{S}$	0.71	-3.70	-2.91
GJR sk$\mathcal{S}$	0.01	-1.81	-1.63

Table with average DM on the differentials.

Note:

Light (dark) gray reports significant outperformance (at the 1% level) of MS (SR).

(2) LEFT-TAIL TEST – RESULTS

	Stocks		
	QL 1%	QL 5%	wCRPS
GARCH $\mathcal{N}$	1.01	-3.51	-9.49
GARCH sk$\mathcal{N}$	0.49	-4.21	-9.75
GARCH $\mathcal{S}$	-2.94	-2.95	-2.70
GARCH sk$\mathcal{S}$	1.38	-3.22	-2.00
GJR $\mathcal{N}$	0.64	-4.99	-9.86
GJR sk$\mathcal{N}$	1.10	-5.25	-10.08
GJR $\mathcal{S}$	0.71	-3.70	-2.91
GJR sk$\mathcal{S}$	0.01	-1.81	-1.63

First **research question**:

- **MS** (significantly) **better**.
- Especially true for **stocks**.

Note:

- GJR is preferred.
- Student is preferred.
- Skewness is preferred.
- SR skewed Student performs remarkably well.

(3) LEFT-TAIL TEST – SETUP

– We dig further into the results to determine **what makes MS attractive** compared to SR.

– We focus on the left tail and compare the weighted CRPS measure for **different models specifications** for MS against SR.

Negative value indicates outperformance of MS.

Light (dark) gray reports significant outperformance of MS (SR).

(3) LEFT-TAIL TEST – RESULTS

MS \ SR	GARCH $\mathcal{N}$	GARCH sk$\mathcal{N}$	GARCH $\mathcal{S}$	GARCH sk$\mathcal{S}$	GJR $\mathcal{N}$	GJR sk$\mathcal{N}$	GJR $\mathcal{S}$	GJR sk$\mathcal{S}$
Panel A: Stocks								
GARCH $\mathcal{N}$	-9.49	-9.67	4.77	4.83	-7.48	-7.43	2.55	2.44
GARCH sk$\mathcal{N}$	-9.55	-9.75	4.39	4.60	-7.58	-7.56	2.36	2.27
GARCH $\mathcal{S}$	-9.80	-10.01	-2.70	-1.69	-8.34	-8.37	-1.17	-1.40
GARCH sk$\mathcal{S}$	-9.54	-9.76	-2.86	-2.00	-8.18	-8.22	-1.19	-1.44
GJR $\mathcal{N}$	-8.93	-9.02	2.86	2.99	-9.86	-10.04	4.92	4.69
GJR sk$\mathcal{N}$	-9.03	-9.19	2.57	2.73	-9.86	-10.08	4.40	4.31
GJR $\mathcal{S}$	-9.50	-9.66	-0.86	-0.61	-10.24	-10.44	-2.91	-3.45
GJR sk$\mathcal{S}$	-9.28	-9.47	-0.25	-0.02	-10.04	-10.28	-1.07	-1.63

– Table with averages (over assets) of a given MS model against another SR model.

(3) LEFT-TAIL TEST – RESULTS

	GARCH				GJR			
MS/SR	$\mathcal{N}$	sk$\mathcal{N}$	$\mathcal{S}$	sk$\mathcal{S}$	$\mathcal{N}$	sk$\mathcal{N}$	$\mathcal{S}$	sk$\mathcal{S}$
Panel A: Stocks								
GARCH $\mathcal{N}$	-9.49	-9.67	4.77	4.83	-7.48	-7.43	2.55	2.44
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GJR sk$\mathcal{S}$	-9.28	-9.47	-0.25	-0.02	-10.04	-10.28	-1.07	-1.63

– **MS dominates** SR with (skew) Normal.

(3) LEFT-TAIL TEST – RESULTS

	GARCH				GJR			
MS/SR	$\mathcal{N}$	sk$\mathcal{N}$	$\mathcal{S}$	sk$\mathcal{S}$	$\mathcal{N}$	sk$\mathcal{N}$	$\mathcal{S}$	sk$\mathcal{S}$
Panel A: Stocks								
GARCH $\mathcal{N}$	-9.49	-9.67	4.77	4.83	-7.48	-7.43	2.55	2.44
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GJR $\mathcal{S}$	-9.50	-9.66	-0.86	-0.61	-10.24	-10.44	-2.91	-3.45
GJR sk$\mathcal{S}$	-9.28	-9.47	-0.25	-0.02	-10.04	-10.28	-1.07	-1.63

- But **MSGARCH** with a (skew) **Normal** distribution is **not able** to jointly account for the switch in the parameters as well as for the **excess of kurtosis** exhibited from the data.
- MSGARCH with a (skew) **Student** is **required**.

SUMMARY

- **MS mechanism** in GARCH models **depends** on the underlying **asset class** on which it is applied.
  - For **stock data**, strong evidence in favor of **MSGARCH.**

    This can be explained by the large (un)conditional kurtosis observed for the log–returns of stock data.
  - Not the case for stock indices and currencies.

- Accounting for the **parameter uncertainty** (*i.e.*, integrating the parameter uncertainty into the predictive distribution) via MCMC is **necessary for stock data**.

CURRENT FOCUS

- **Multi-step** ahead forecasts:
  Impact of mean-reversion speed of GARCH vs. MSGARCH.

- Regime-switches in **volatility only**:
  Breaks in volatility dynamics vs. changes in conditional distributions.

- **Additional data** sets:
  - Emerging markets.
  - Commodities.

- **3-state** MSGARCH:
  Number of regimes and asset class?

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https://ssrn.com/abstract=2918413

https://CRAN.R-project.org/package=MSGARCH

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