# Coverage Testing in Non-Stationary Time Series Forecasts

This repository accompanies the following **submitted manuscript**:

**Title:**
***Testing Marginal and Conditional Coverage in Non-Stationary Time Series Forecasts through VaR Backtesting***
**Author:** Konrad Retzlaff
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## Project Summary

This project introduces a **statistical testing framework** for evaluating **Conformal Prediction (CP)** under **non-stationary time series**. Inspired by Value-at-Risk (VaR) backtesting, we assess CP methods using **formal hypothesis tests** for marginal validity, temporal independence, and conditional coverage.

We evaluate CP methods on:

- **Synthetic data** with changepoints and drift *(Barber et al., 2023)*
- **Electricity price forecasts** (ELEC2 dataset from Kaggle)
- **S&P 100 stock forecasts** (retrieved from Yahoo Finance API)

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## Folder Structure

```
data/
│
├── ELEC2/
│   ├── elec_simulation_CP.csv
│   ├── elec_simulation_nexCP_LS.csv
│   └── elec_simulation_nexCP_WLS.csv
│
├── Financial Timeseries/
│   ├── pred_calib.csv
│   ├── pred_test.csv
│   ├── quantile_calib.csv
│   ├── quantile_test.csv
│   └── Wide_S_P_100_forecasts.csv
│
└── Synthetic Data/
    ├── simulation_CP_LS.csv
    ├── simulation_nexCP_LS.csv
    └── simulation_nexCP_WLS.csv
```

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## Repository Files

| File | Description |
|---|---|
| `ConformalPredictor.py` | Implements Split CP, CQR, and ACI |
| `TestingFramework.py` | Contains all 8 formal backtests |
| `Synthetic_data.ipynb` | Runs CP+LS, NexCP+LS, NexCP+WLS on synthetic data (Barber et al.) |
| `Elec_data.ipynb` | Applies all 3 Barber methods to the ELEC2 dataset |
| `Modeltrainer.ipynb` | Trains LightGBM model on S&P 100 stock return data |
| `Calib_Analysis.ipynb` | Applies Split CP, CQR, ACI and all tests to financial data |
| `requirements.txt` | Python packages needed to reproduce results |

## CP Methods Used

### Synthetic & ELEC2 (Barber et al., 2023)

- **CP+LS**: Full Conformal Prediction with Least Squares
- **NexCP+LS**: Non-exchangeable CP with exponential weights
- **NexCP+WLS**: Non-exchangeable CP with Weighted Least Squares

### Financial Time Series (S&P 100)

- **Split CP**
- **Conformalized Quantile Regression (CQR)**
- **Adaptive Conformal Inference (ACI)**

## Statistical Tests (8 total, grouped in 4 categories)

| Category | Purpose | Included Tests |
|---|---|---|
| **1. Marginal Coverage** | Is average coverage close to target rate α? | • Binomial Test (Lower)<br>• Binomial Test (Upper)<br>• Binomial Test (Two-sided)<br>• First Geometric Test (for parameter (a)) |
| **2. Violation Independence** | Are violations temporally independent? | • Second Geometric Test (for parameter (b)) |
| **3. Conditional Coverage** | Are violations predictable from inputs? | • Joint Geometric Test (for (a) and (b))<br>• Dynamic Binary Test |
| **4. Interval Score Comparison** | Are intervals both valid and efficient? | • Comparative Interval-Score Test (Diebold-Mariano) |

## Installation

```
git clone https://github.com/KonradRtz/Coverage-Testing-in-Non-stationary-Time-Series.git
cd Coverage-Testing-in-Non-stationary-Time-Series
pip install -r requirements.txt
```

Dependencies include:
`numpy`, `pandas`, `scipy`, `matplotlib`, `scikit-learn`, `lightgbm`

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# How to Run

## Synthetic Data

Run `Synthetic_data.ipynb` to evaluate CP+LS, NexCP+LS, and NexCP+WLS.
Default predictions are included in `data/Synthetic Data/`.

> **Alternative**: You may regenerate synthetic predictions using the official implementation by Barber et al.:
> https://rinafb.github.io/code/nonexchangeable_conformal.zip
> Convert the output to:
>
> ```
> method, time, true_y, lower_bound, upper_bound, violation
> ```

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## Electricity Forecasts (ELEC2)

Run `Elec_data.ipynb` using files in `data/ELEC2/`.
You may optionally regenerate predictions using the same external code and formatting as above.

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## Financial Forecasts

1. Train forecasting model in `Modeltrainer.ipynb`
2. Evaluate with Split CP, CQR, and ACI in `Calib_Analysis.ipynb` using Yahoo Finance-based data

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# Output

Results include full statistical test reports, p-values, and interval score comparisons per method.

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# References


- **Barber, Candès, Ramdas, Tibshirani (2023)**
  *Conformal Prediction Beyond Exchangeability*
  arXiv:2202.13415

- **Romano, Patterson, Candès (2019)**
  *Conformalized Quantile Regression*
  arXiv:1905.03222

- **Gibbs & Candès (2021)**
  *Adaptive Conformal Inference*
  arXiv:2106.00170

- **ELEC2 Dataset**
  https://www.kaggle.com/datasets/yashsharan/the-elec2-dataset


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## Contact

kretzlaff.student@maastrichtuniversity.nl