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Research article

Forecasting hourly WTI oil front monthly price volatility densities

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Supplementary

Appendix

The appendix focuses on daily data for the period January 2023 to April 2023. Figure A.1 plots the three (2+1) volatility factors. Table A reports a static forecast with associated forecast fit measures. Figure A.2 reports the fit, actual, and standard errors. Table A.2 reports the measures for the three machine learning techniques: Lasso, Ridge, and Decision Forest. We have not optimised the hyperparameter values for optimal performance. Figure A.3 reports the three machine learning techniques together with the static forecast, including two standard errors. Figures A.3 and A.4 report a neural network for V1t and V2t, respectively.

Table A.1. Characteristics volatility-factors WTI oil daily prices.

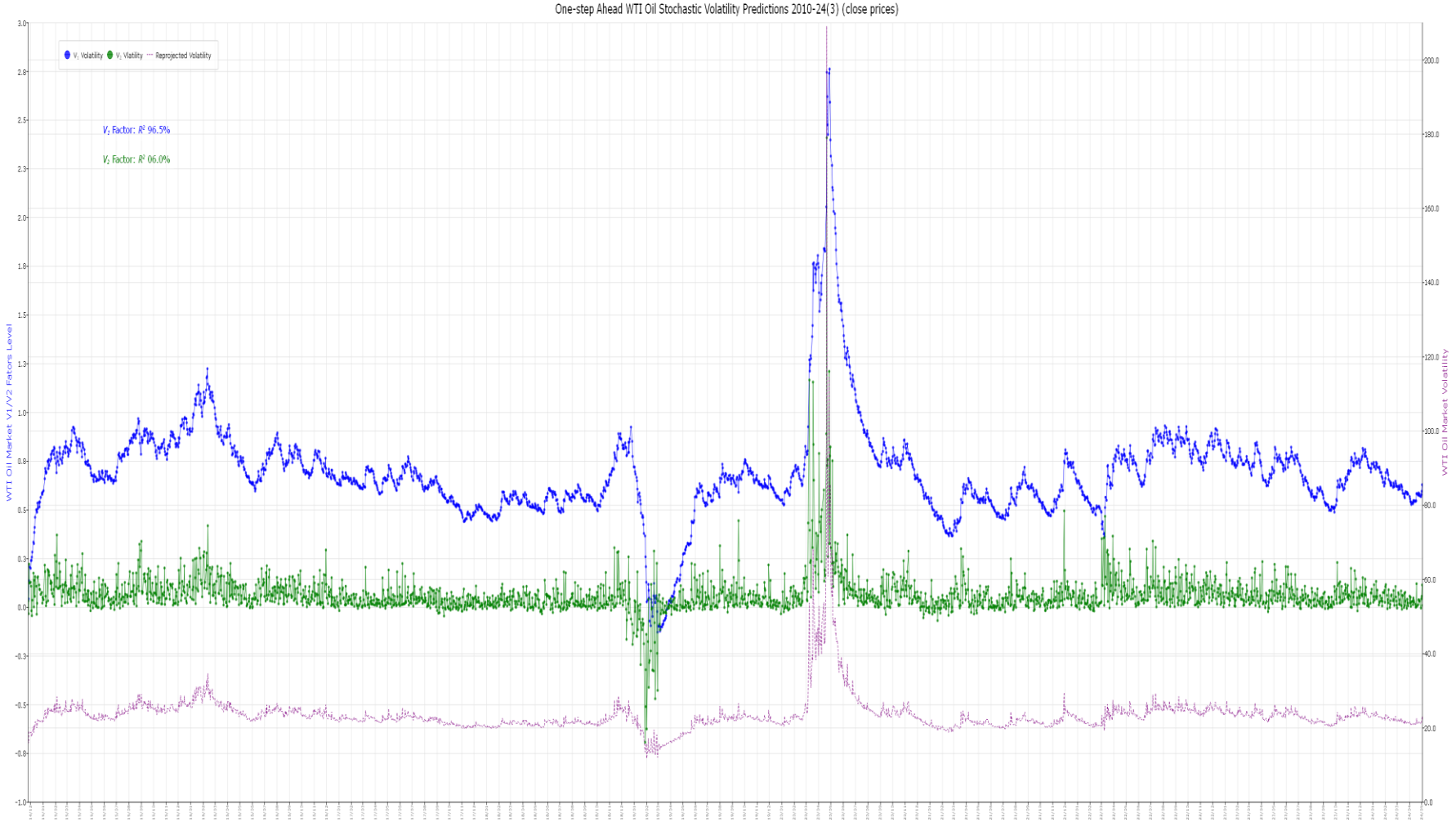
Category	Mean (all)/ Mode	Median Std.dev.	Maximum/ Minimum	Moment Kurt/Skew	Quantile Kurt/Skew	Quantile Normal	Cramer-Mises	Serial dep Q(12)	VaR (1%; 2.5%)
	0.69165	0.66716	2.7626	14.6064	−0.08342	2.9556	4.9654	25099.4	0.0031
Factor		0.26304	−0.1275	2.32520	0.07476	{0.2281}	{0.0000}	{0.0000}	0.1469
V_{1t}	BDS-*Z*-statistic (*e* = 1)				Phillips-	Augmented		Breusch-	CVaR
	m=2	m=3	m=4	m=5	Perron	DF-test		Godfrey	(1%; 2,5%)
	122.9288	143.0326	169.4305	207.3663	−4.2775	−4.5796		9022.9	−0.0690
	{0.0000}	{0.0000}	{0.0000}	{0.0000}	{0.0034}	{0.0011}		{0.0000}	0.0148
Category	Mean (all)/ Mode	Median Std.dev.	Maximum/ Minimum	Moment Kurt/Skew	Quantile Kurt/Skew	Quantile Normal	Cramer-von-Mises	Serial dependence Q(12)	VaR (1%; 2,5%)
	0.06585	0.04679	2.4103	105.5532	0.06215	17.1314	30.839	132.798	−0.1153
Factor		0.11034	−0.6927	6.21107	0.20374	{0.0002}	{0.0000}	{0.0000}	−0.0265
V_{2t}	BDS-*Z*-statistic (*e* = 1)				Phillips-	Augmented		Breusch-	CVaR
	m=2	m=3	m=4	m=5	Perron	DF-test		Godfrey	(1%; 2,5%)
	11.4337	12.8488	13.9678	15.1503	−50.214	−13.9766		10.8923	−0.2912
	{0.0000}	{0.0000}	{0.0000}	{0.0000}	{0.0000}	{0.0000}		{0.0000}	−0.1470
Category	Mean (all)/ Mode	Median Std.dev.	Maximum / Minimum	Moment Kurt/Skew	Quantile Kurt/Skew	Quantile Normal	Cramer-von-Mises	Serial dependence Q(12)	VaR (1%; 2,5%)
	23.61411	22.79810	209.1165	298.8589	−0.02123	5.5495	19.797	9418.18	15.223
Volatility		6.54268	11.7859	13.10155	0.11677	{0.0624}	{0.0000}	{0.0000}	17.192
$\exp(V_{1t}+V_{2t})$	BDS-*Z*-statistic (*e* = 1)				Phillips-	Augmented		Breusch-	CVaR
(yearly)	m=2	m=3	m=4	m=5	Perron	DF-test		Godfrey	(1%; 2,5%)
	67.1534	72.5761	77.3409	83.5409	−41.978	−5.6931		258.117	12.837
	{0.0000}	{0.0000}	{0.0000}	{0.0000}	{0.0000}	{0.0000}		{0.0000}	14.825

Table A.2. WTI oil daily volatility ordinary OLS (*qr*) step ahead fit measures.

Daily Estimated Stochastic Volatility Forecast Fit Measures (Eviews)				
Contracts	Error Measures	Factor 1 V_1t	Factor 2 V_2t	Reprojected Volatility
	Root Mean Square Error (RMSE)	0.01436	0.03857	0.16740
	Mean absolute Error (MAE)	0.01184	0.03050	0.13308
	Mean absolute percent error (MAPE)	1.7662	1551.470	7.21080
Ftse100	Theil inequality coefficient (U1)	0.01070	0.34703	0.04462
spot	Bias proportion	0.0007	0.0415	0.0378
index	Variance Proportion	0.0001	0.1692	0.1225
(UK)	Covariance Proportion	0.9992	0.7893	0.8398
	Theil U2 Coefficient	0.93584	2.31389	1.79626
	Symmetric MAPE	1.7548	73.206	7.00502

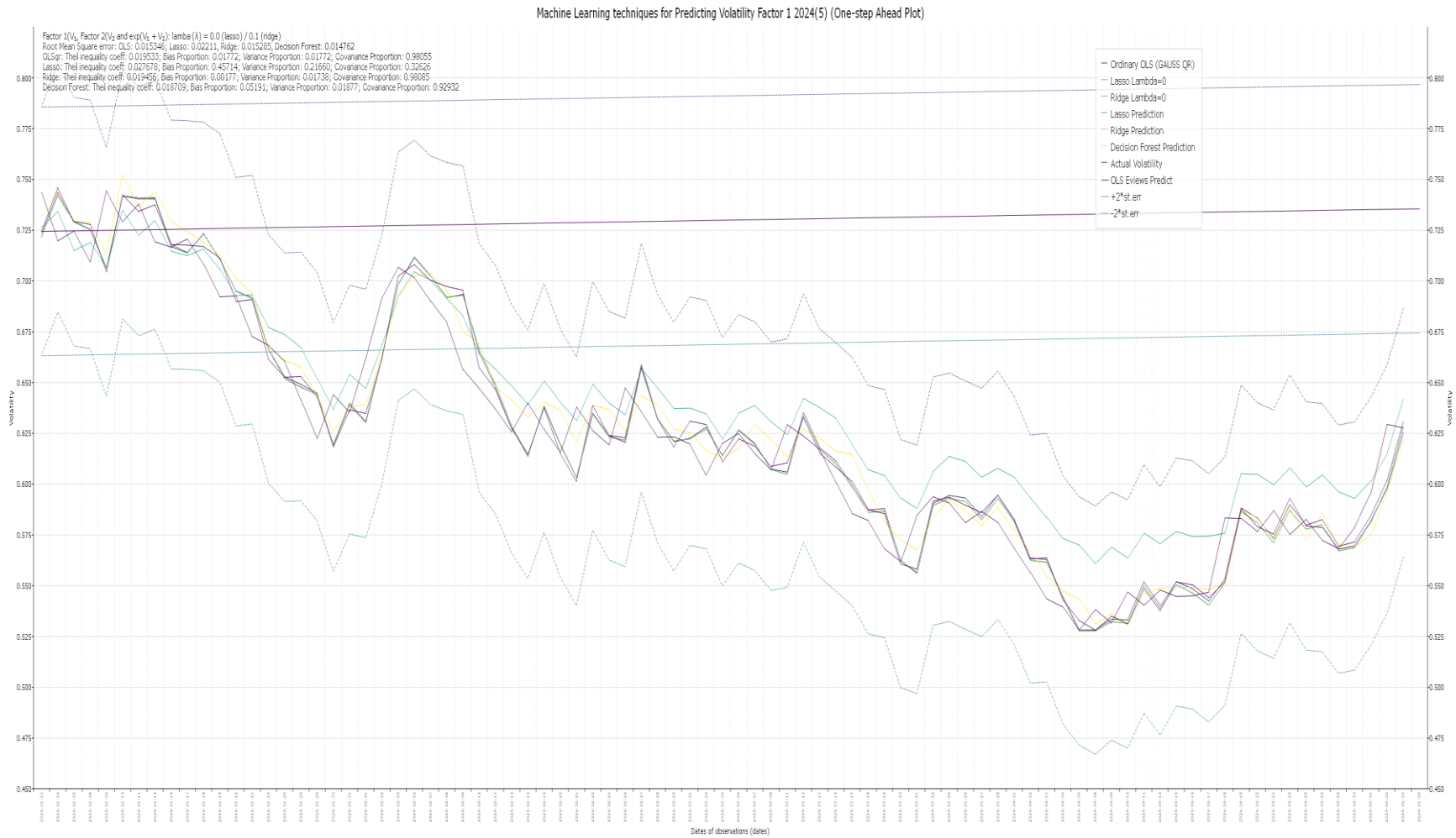
Table A.3. Projection fit for machine learning regression models.

Daily Estimated Stochastic Volatility Forecast Fit Measures						
Category		Factor 1 V_{1t}		Factor 2 V_{2t}		Reprojected Volatility ($e^{(V1t+V2t)}$)	
Lasso Regression (l = 0.0)							
Ridge Regression (l = 0.0)	RMSE	0.015346		0.036834		1.09599	
	MSE	0.011879		0.029463		0.87104	
	MAPE	1.878833		455.3575		3.89490	
	Theil inequality coefficient 1 (U1)	0.019533		6.40554		0.00111 3	
	Bias Proportion		0.00173		0.04434		0.00003
	Variance Proportion		0.01772		0.17177		0.19182
	Covariance Proportion		0.98055		0.78389		0.80815
	Theil U2 Coefficient	0.62386		0.48754		3.07155	
	Symmetric MAPE	0.02240		0.74716		0.04623	
Lasso Regression (l = 0.05)	RMSE	0.022211		0.039863		0.64344	
	MSE	0.019648		0.034452		0.50198	
	MAPE	3.267560		541.2264		2.23897	
	Theil inequality coefficient 1 (U1):	0.027678		5.68713		0.00406 8	
	Bias Proportion		0.45714		0.29925		0.00407
	Variance Proportion		0.21660		0.63805		0.01897
	Covariance Proportion		0.32626		0.06271		0.97696
	Theil U_2 Coefficient	1.46367		1.11529		1.06054	
	Symmetric MAPE	0.03662		0.75878		0.02662	
Ridge Regression (l = 0.1)	RMSE	0.015285		0.036715		1.08430	
	MSE	0.011832		0.029404		0.86094	
	MAPE	1.871757		455.7302		1.66536	
	Theil inequality coefficient 1 (U1):	0.019456		6.38953		0.00110 1	
	Bias Proportion		0.00177		0.04459		0.00003
	Variance Proportion		0.01738		0.17531		0.18838
	Covariance Proportion		0.98085		0.78010		0.81159
	Theil U2 Coefficient	0.61936		0.47915		3.00591	
	Symmetric MAPE	0.02231		0.74569		0.04570	
Decision Forest							
	RMSE	0.014762		0.033259		0.47812	
	MSE	0.012508		0.027112		0.37235	
	MAPE	1.991256		337.5840		1.66536	
	Theil inequality coefficient 1 (U1):	0.018709		6.59757		0.00048 5	
	Bias Proportion		0.05191		0.00510		0.01146
	Variance Proportion		0.01877		0.43315		0.00497
	Covariance Proportion		0.92932		0.56175		0.98356
	Theil U2 Coefficient	0.57565		0.61513		0.59142	
	Symmetric MAPE	0.02353		0.72987		0.01974	

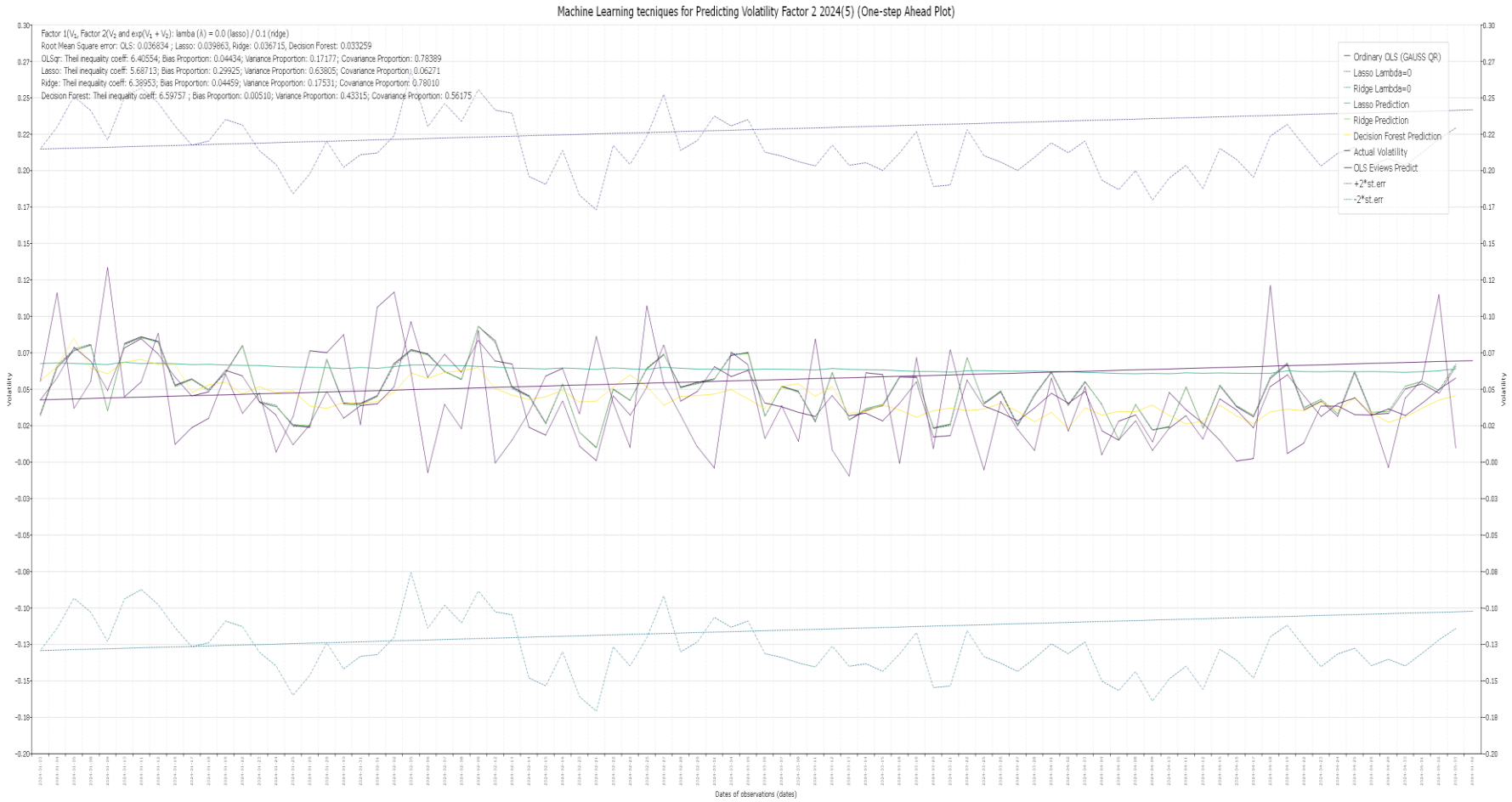


See Figure 8 above for interpretation of volatility time series.

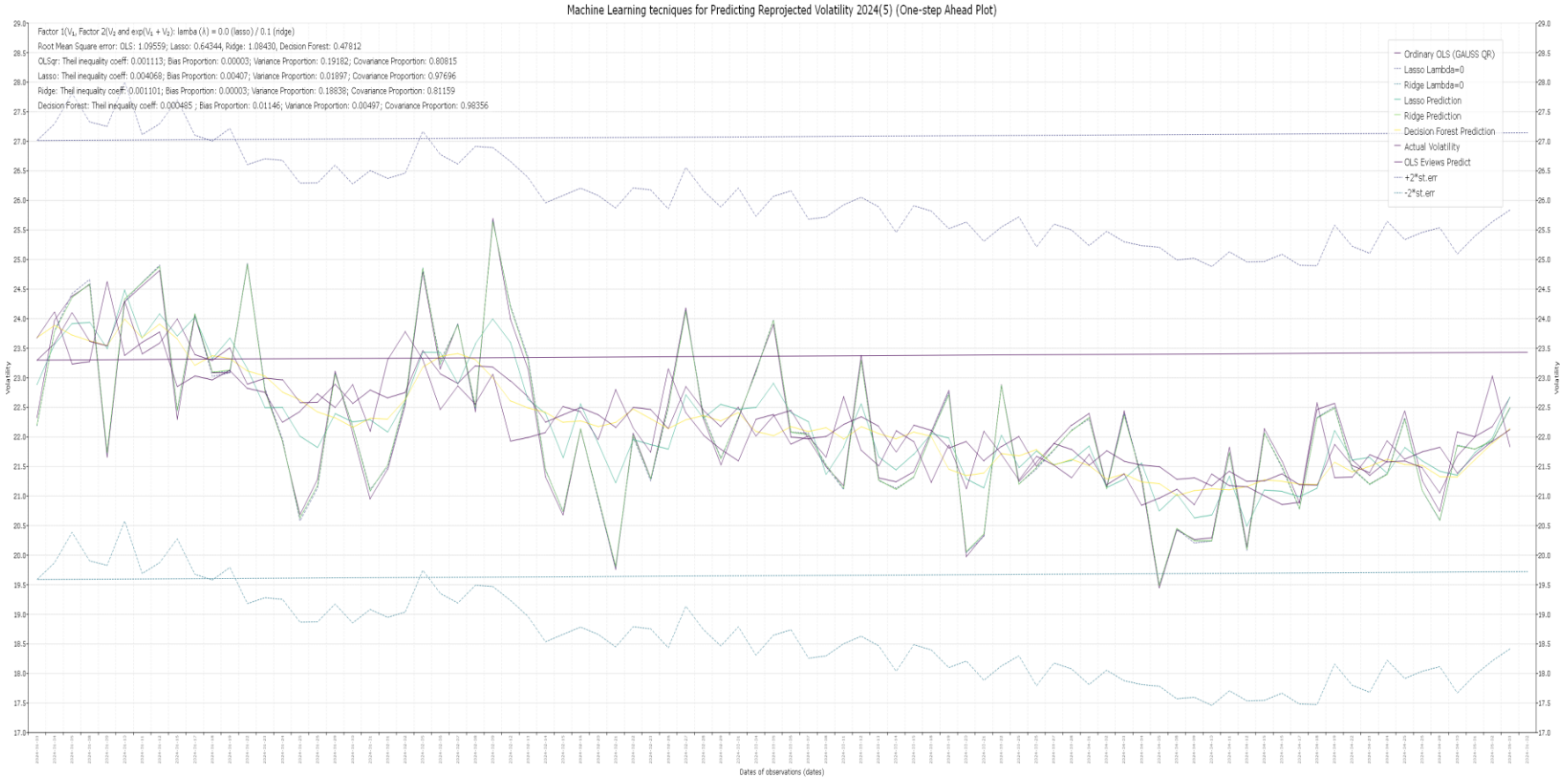
Figure A.1. Daily volatility paths for two factors (V_1 and V_2) and re-projected exp(V_1+V_2) volatility (2014–2024(3)).



See Figure 10 above for interpretation of volatility time series.

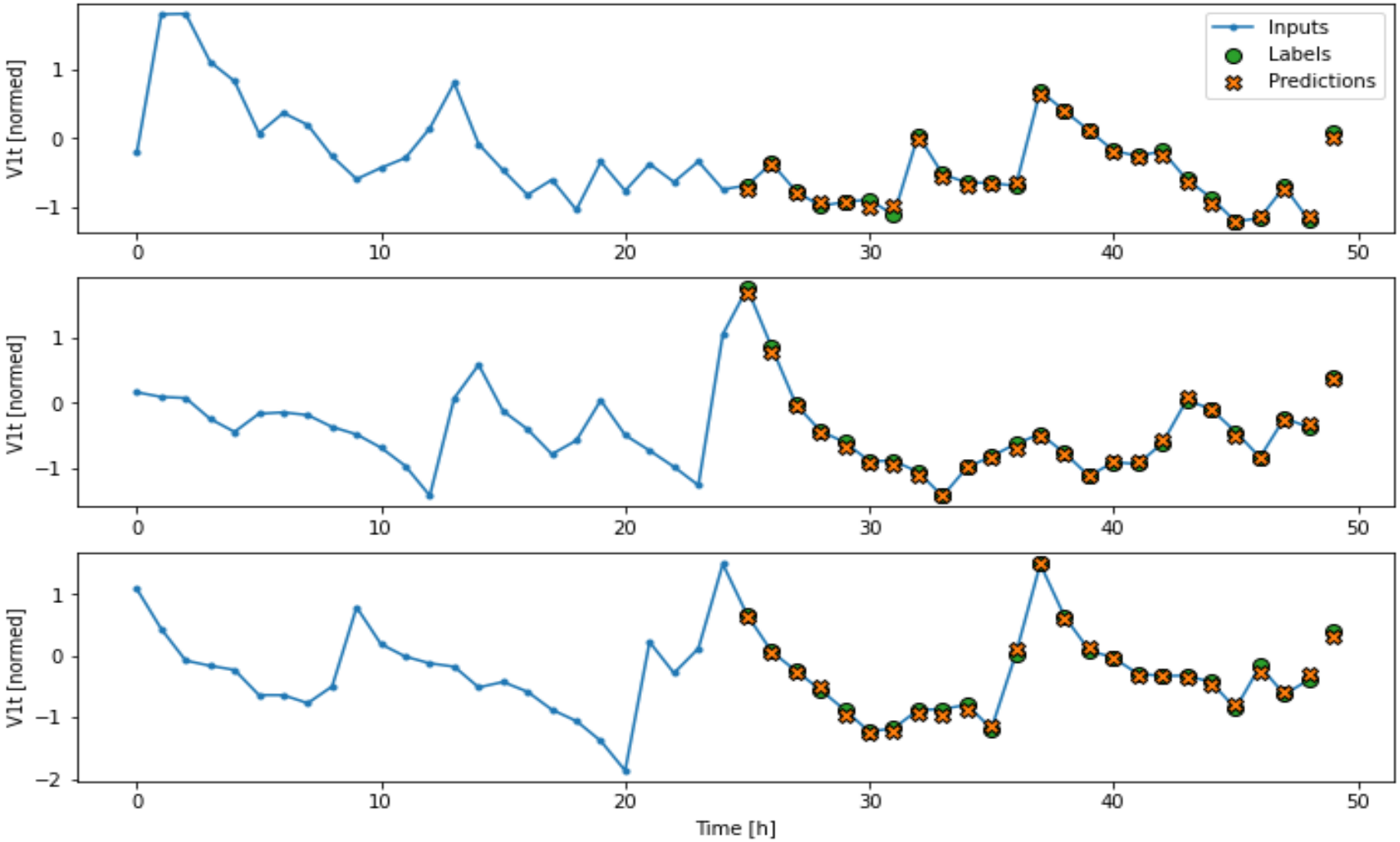


See Figure 10 above for interpretation of volatility time series.

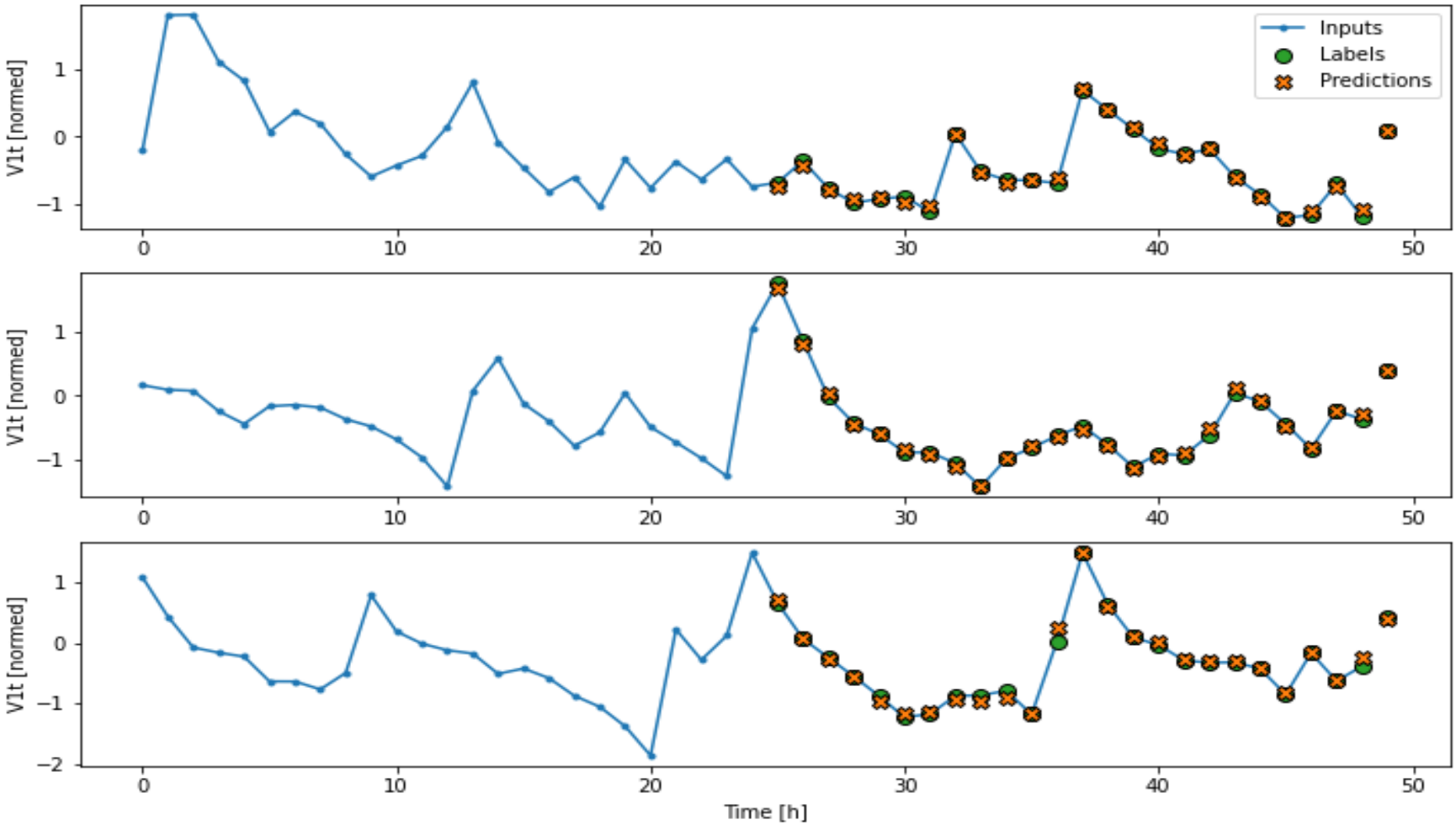


See Figure 10 above for interpretation of volatility time series.

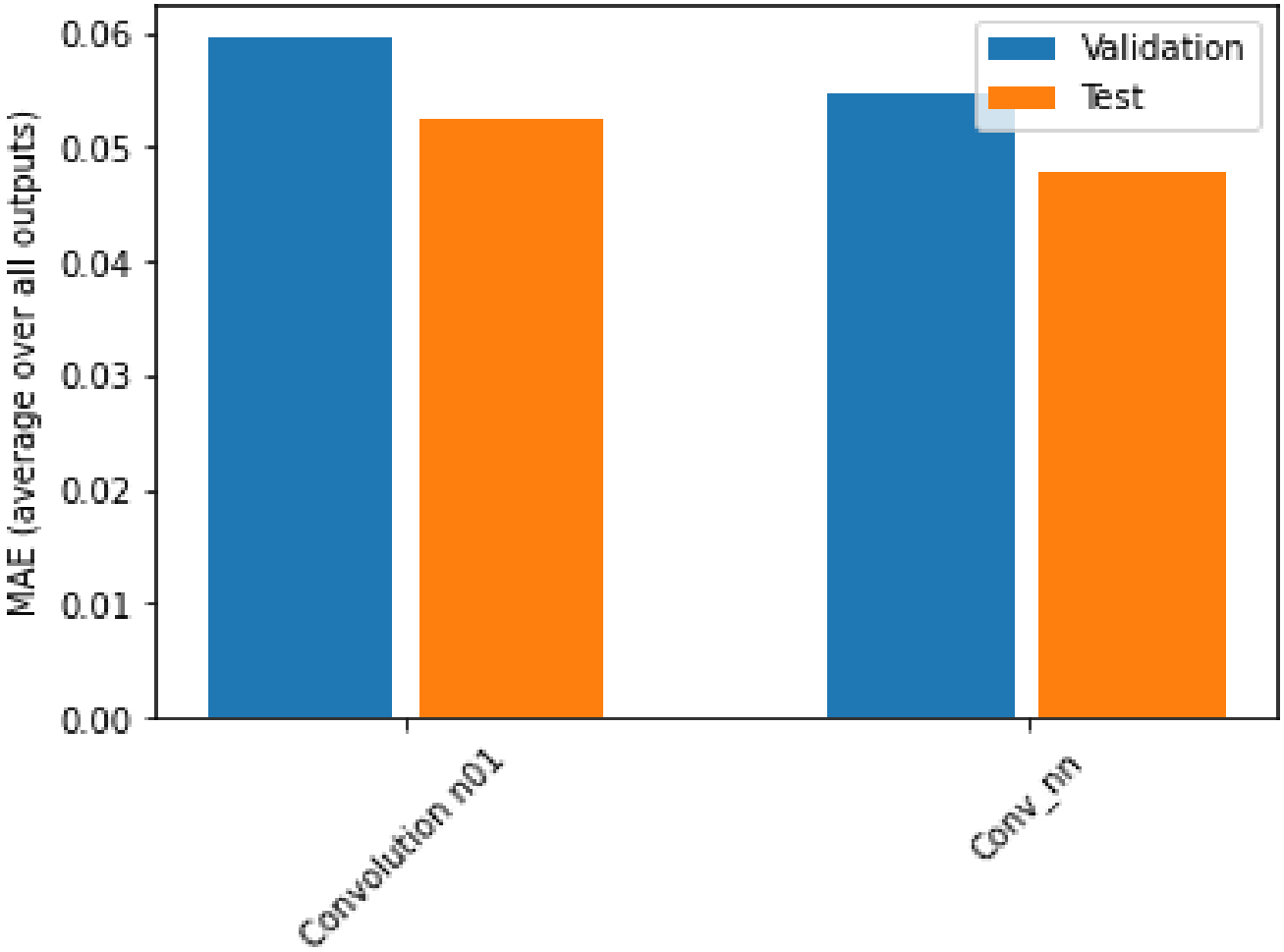
Figure A.2. Daily machine learning prediction model fits.



See Figure 11 above for interpretation of volatility time series

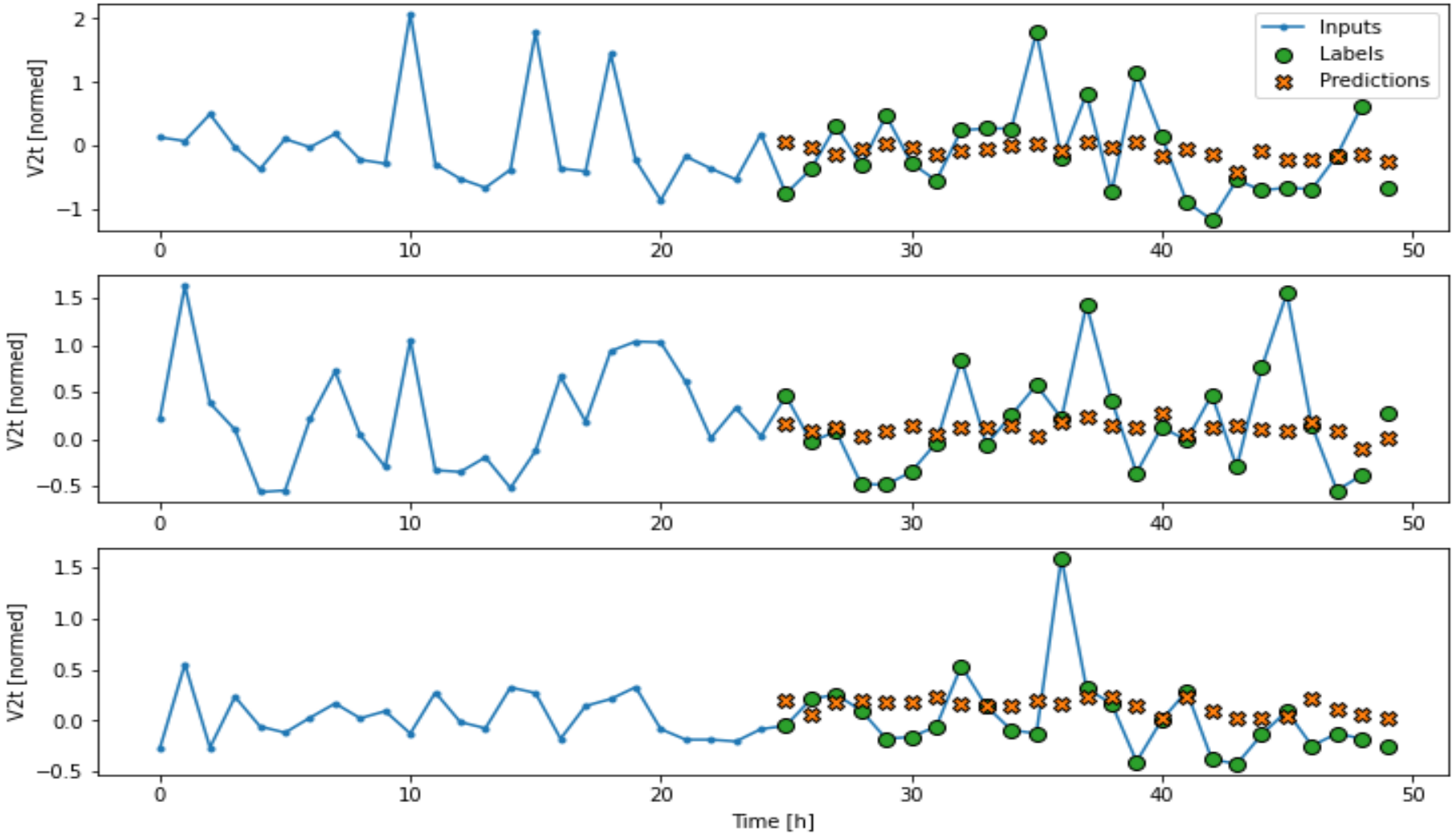


See Figure 11 above for interpretation of volatility time series

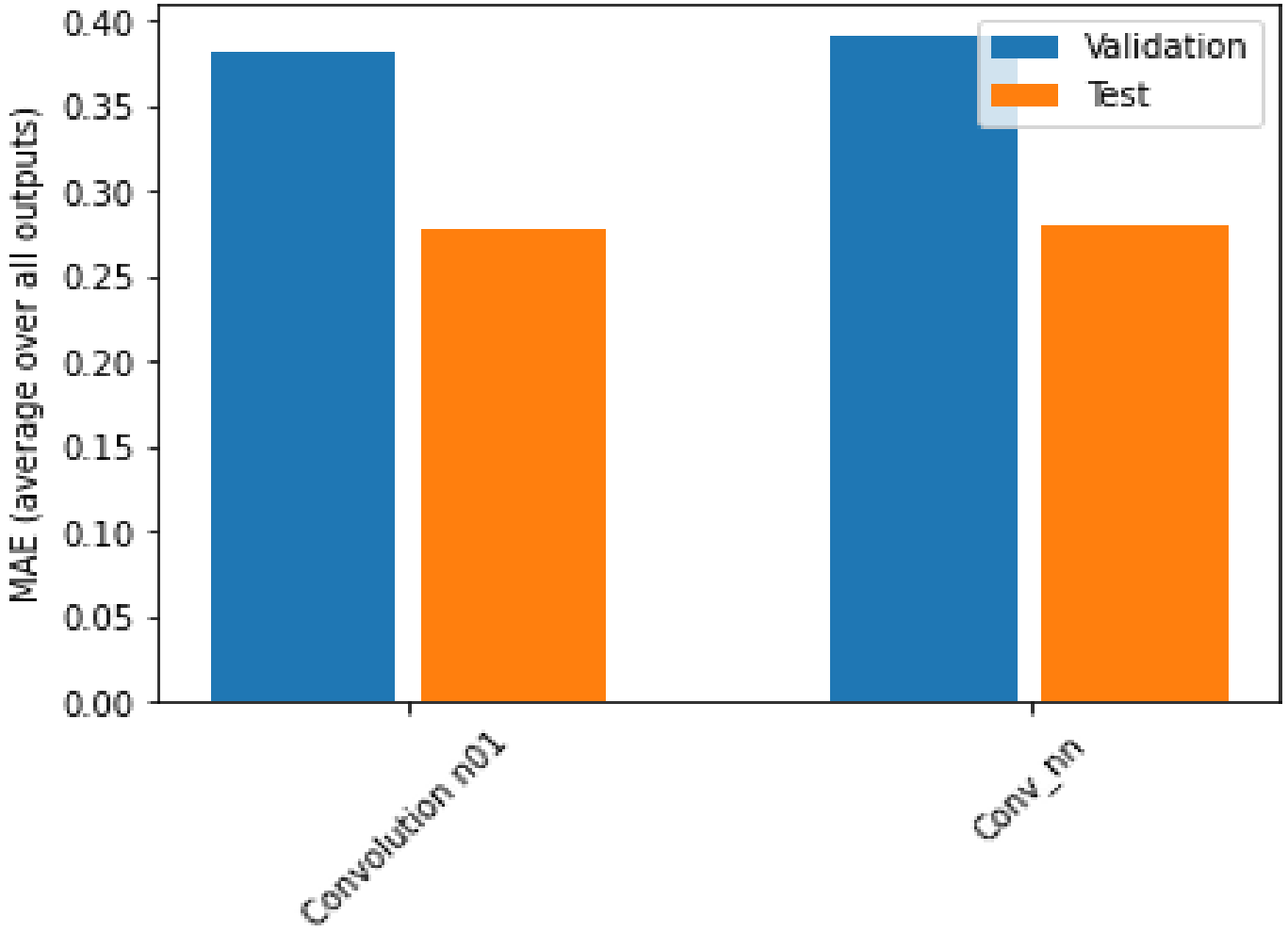


See Figure 11 above for interpretation of volatility time series.

Figure A.3. Daily neural network CNN/RNN/LSTM results and performance for WTI oil V_{1t}.



See Figure 12 above for interpretation of volatility time series



See Figure 12 above for interpretation of volatility time series.

Figure A.4. Daily neural network CNN/RNN/LSTM results and performance for WTI oil V_{2t}.

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