Feature selection and deep neural networks for stock price direction forecasting using technical analysis indicators

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Outline

Stock price forecasting

Efficient-market hypothesis (weak form): The present prices reflect all information of past prices (random walk)

- Thus, based on this assumption, indicators based on past prices and trading volumes have no consistent predictive power for future stock price variations

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- Thus, based on this assumption, indicators based on past prices and trading volumes have no consistent predictive power for future stock price variations
- Still, a lot of people (still) try! (Kara et al. (2011); Chen et al. (2014); Laboissiere et al. (2015); Patel et al. (2015); Chen et al. (2017); Zhong and Enke (2017), among (many) others)

Stock price forecasting and machine learning

In particular, machine learning methods (mainly Artificial Neural Networks and Support Vector Machines) are one of the more researched topics in the recent financial forecasting literature (Henrique et al., 2019).

- Many papers focused on both direction and price prediction, as well as using both individual stocks and market indexes as target assets.

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- Many papers focused on both direction and price prediction, as well as using both individual stocks and market indexes as target assets.
- Specifically using technical analysis indicators as input variables: Kara et al. (2011), Chen et al. (2014), Patel et al. (2015), Gorenc Novak and Velušček (2016), Chiang et al. (2016), Chen et al. (2017), among others.

Main contributions

1. Compendium of technical analysis indicators considered in recent scientific articles on stock prices prediction and market professionals
2. Evaluate the relative importance of each mapped technical analysis indicator
3. Test the empirical performance of deep neural networks for stock price direction prediction and the profitability from the yielded strategies

Outline

The "Factor Zoo"

There is a "zoo" of candidate factors for asset pricing models (Cochrane, 2011)

- Harvey et al. (2016) listed 316 factors used by the literature to model the cross-section of expected financial returns

Another "Factor Zoo"

There is another "factor zoo" composed by technical analysis indicators used as independent variables in machine learning models for forecasting the value/direction of financial stock prices/market indexes

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- 51 technical analysis indicators were used as predictors in papers published in high impact journals between 1999 and 2018
- Another 74 indicators are used by the "trader side" – specialized websites that offer financial services and technical analysis softwares

Feature selection in finance

Garbage in, garbage out! (bias-variance dilemma)

- Harvey et al. (2016) listed 316 factors, most of which did not bring significant improvements on the models' performance
- Kozak et al. (2017) tested 130 factors and their interactions up to degree-3 polynomials, finding that a small number of principal components are able to capture almost all of the out-of-sample explanatory power

Feature selection in finance

- Hwang and Rubesam (2018) searched the best model from a set of 83 factors, finding out that only 5 to 6 showed actual significance on explaining the assets returns. Additionally, the study showed that the only factor that was consistently selected throughout the periods was the excess market return
- The market systematic risk represents a principal component in financial covariance matrices with far more explained variance then the remaining ones, while the vast majority of eigenvalues are statistically “noise” (Laloux et al., 1999; Sensoy et al., 2013)

"Factor Zoo" of technical analysis indicators

Variable	References
Simple moving average	Chang and Fan (2008), Chang, Liu, Lin, Fan, and Ng (2009), Huang and Tsai (2009) and Thawornwong, Enke, and Dagli (2003)
	Chang et al. (2012), Kara, Boyacioglu, and Baykan (2011), Vanstone and Finnie (2010) and Yu, Chen, Wang, and Lai (2009)
	Chen, Cheng and Tsai (2014), Creamer (2012), de Oliveira, Nobre, and Zárate (2013) and Patel, Shah, Thakkar, and Kotecha (2015a)
	Chiang, Enke, Wu, and Wang (2016), Gorenc Novak and Velušček (2016), Patel, Shah, Thakkar, and Kotecha (2015b) and Weng, Ahmed, and Megahed (2017)
	Alhashel, Almudhaf, and Hansz (2018) and Henrique, Sobreiro, and Kimura (2018)
Weighted moving average	Gorenc Novak and Velušček (2016), Kara et al. (2011) and Patel et al. (2015a, 2015b)
	Alhashel et al. (2018) and Henrique et al. (2018)
Exponential moving average	Ang and Quek (2006), Tay and Cao (2001), Vanstone and Finnie (2010) and Yu et al. (2009)
	Chen, Xiao, Sun, and Wu (2017), Creamer (2012), Gorenc Novak and Velušček (2016) and Ticknor (2013)
	Alhashel et al. (2018), Nakano, Takahashi, and Takahashi (2018) and Weng et al. (2017)
	Creamer (2012), Kara et al. (2011), Kim (2003), Kim and Han (2000) and Yu et al. (2009)
Momentum	Chen, Cheng et al. (2014), de Oliveira et al. (2013), Patel et al. (2015a) and Patel et al. (2015b)
	Chiang et al. (2016), Gorenc Novak and Velušček (2016) and Weng et al. (2017)
	Chang et al. (2009), Kim (2003), Kim and Han (2000), Kwon and Moon (2007) and Thawornwong et al. (2003)
Stochastic K%	Huang and Tsai (2009), Kara et al. (2011), Vanstone and Finnie (2010) and Yu et al. (2009)
	Chang et al. (2012), Chen, Kuo, Huang and Chen (2014), de Oliveira et al. (2013) and Ticknor (2013)
	Patel et al. (2015a, 2015b)
	Alhashel et al. (2018) and Nakano et al. (2018)
	Chang and Fan (2008) and Kim (2003), Kim and Han (2000), Kwon and Moon (2007)
Stochastic D%	Chang et al. (2009), Huang and Tsai (2009), Kara et al. (2011) and Yu et al. (2009)
	Chang et al. (2012), Chen, Kuo et al. (2014), de Oliveira et al. (2013) and Ticknor (2013)
	Nakano et al. (2018) and Patel et al. (2015a, 2015b)
Slow stochastic D%	Kim (2003), Kim and Han (2000) and Yu et al. (2009)
	Armano, Marchesi, and Murru (2005), Kim (2003), Kim and Han (2000) and Thawornwong et al. (2003)
Relative strength index	Chang and Fan (2008), Chang et al. (2009), Huang and Tsai (2009) and Kwon and Moon (2007)
	Kara et al. (2011), Vanstone and Finnie (2010) and Yu et al. (2009)
	Chang et al. (2012), Creamer (2012), de Oliveira et al. (2013) and Ticknor (2013)
	Chen, Cheng et al. (2014), Gorenc Novak and Velušček (2016) and Patel et al. (2015a, 2015b)
	Alhashel et al. (2018), Nakano et al. (2018) and Weng et al. (2017)
	Henrique et al. (2018)
	Armano et al. (2005), Kwon and Moon (2007), Tay and Cao (2001) and Thawornwong et al. (2003)
Moving average convergence–divergence	Chang and Fan (2008), Chang et al. (2009), Huang and Tsai (2009) and Yu et al. (2009)
	Chang et al. (2012), Creamer (2012), Kara et al. (2011) and Vanstone and Finnie (2010)
	Chen, Cheng et al. (2014), Chen, Kuo et al. (2014), de Oliveira et al. (2013) and Patel et al. (2015a)
	Alhashel et al. (2018), Chiang et al. (2016), Nakano et al. (2018) and Patel et al. (2015b)
William's R%	Chang et al. (2009), Huang and Tsai (2009) and Kim (2003), Kim and Han (2000)
	Chang et al. (2012), Kara et al. (2011), de Oliveira et al. (2013) and Ticknor (2013)
	Alhashel et al. (2018), Chen, Cheng et al. (2014) and Patel et al. (2015a, 2015b)
Accumulation/Distribution oscillator	Kara et al. (2011), Kim (2003), Kim and Han (2000) and Yu et al. (2009)
	Alhashel et al. (2018), Henrique et al. (2018) and Patel et al. (2015a, 2015b)
	Kara et al. (2011), Kim (2003), Kim and Han (2000) and Yu et al. (2009)
Commodity channel index	Alhashel et al. (2018), Gorenc Novak and Velušček (2016) and Patel et al. (2015a, 2015b)
Rate of change	Armano et al. (2005), Kim (2003), Kim and Han (2000) and Tay and Cao (2001)
	Chang et al. (2009), Creamer (2012), Gorenc Novak and Velušček (2016), Weng et al. (2017) and Yu et al. (2009)
	Alhashel et al. (2018)
Disparity	Kim (2003), Kim and Han (2000), Weng et al. (2017) and Yu et al. (2009)
Price oscillator	Kim (2003), Kim and Han (2000) and Yu et al. (2009)
Psychological line	Chang and Fan (2008), Chen, Cheng et al. (2014) and Huang and Tsai (2009)
Directional indicator up	Huang and Tsai (2009)
Directional indicator down	Huang and Tsai (2009)
Bias	Chang and Fan (2008), Chang et al. (2009, 2012), Chen, Cheng et al. (2014) and Huang and Tsai (2009)
Volume Ratio	Huang and Tsai (2009)
A Ratio	Huang and Tsai (2009)
B Ratio	Huang and Tsai (2009)
Average true range	Henrique et al. (2018) and Vanstone and Finnie (2010)
Bollinger band upper	Alhashel et al. (2018), Creamer (2012) and de Oliveira et al. (2013)
Bollinger band lower	Alhashel et al. (2018), Creamer (2012) and de Oliveira et al. (2013)
Directional movement indicator	Alhashel et al. (2018)
Keltner channel upper band	Alhashel et al. (2018)
Keltner channel lower band	Alhashel et al. (2018)
Triangular moving average	Alhashel et al. (2018)
Moving average envelope upper	Alhashel et al. (2018)
Moving average envelope lower	Alhashel et al. (2018)
Rex oscillator	Alhashel et al. (2018)
Negative volume index	Creamer (2012)
Positive volume index	Creamer (2012)
Volume adjusted moving average	Chavarnakul and Enke (2009)
Highest price ratio	Vanstone and Finnie (2010)
Lowest price ratio	Vanstone and Finnie (2010)
Opening price	de Oliveira et al. (2013)
Closing price	de Oliveira et al. (2013)
Minimum price	de Oliveira et al. (2013)
Minimum price	de Oliveira et al. (2013)
Volume	Chang et al. (2009), de Oliveira et al. (2013) and Gorenc Novak and Velušček (2016)
Volume momentum	Chiang et al. (2016)
Moving price level percentage	Chiang et al. (2016)
Percent price oscillator	Chiang et al. (2016)
Parabolic stop and reverse	Alhashel et al. (2018) and Gorenc Novak and Velušček (2016)
On balance volume	Creamer (2012), Nakano et al. (2018), de Oliveira et al. (2013) and Tay and Cao (2001)
Volatility	Tay and Cao (2001)
Money flow index	Thawornwong et al. (2003)
Variance ratio	Yu et al. (2009)
Linear regression slope	Yu et al. (2009)

Variable	References
Acceleration band up	Trading Technologies (2019)
Acceleration band down	Trading Technologies (2019)
Accumulation/Distribution index	Fidelity Investments (2019) and Trading Technologies (2019)
Money flow multiplier	StockCharts (2019)
Accumulation distribution line	StockCharts (2019) and TradingView (2019)
Absolute price oscillator	Fidelity Investments (2019) and Trading Technologies (2019)
Aroon indicator positive	StockCharts (2019) and Trading Technologies (2019)
	Fidelity Investments (2019) and TradingView (2019)
Aroon indicator negative	StockCharts (2019) and Trading Technologies (2019)
	Fidelity Investments (2019) and TradingView (2019)
Aroon oscillator	StockCharts (2019) and Trading Technologies (2019)
Average directional movement index	StockCharts (2019) and Trading Technologies (2019)
	Fidelity Investments (2019)
Average true range Percent	Fidelity Investments (2019)
Average volume	Fidelity Investments (2019)
Bollinger band width	Fidelity Investments (2019) and StockCharts (2019)
	TradingView (2019)
Bollinger band %B	Fidelity Investments (2019) and StockCharts (2019)
	TradingView (2019)
Band width	Trading Technologies (2019)
Chaikin money flow	Fidelity Investments (2019) and StockCharts (2019)
	TradingView (2019)
Chaikin oscillator	StockCharts (2019) and TradingView (2019)
Chaikin volatility	Fidelity Investments (2019)
Chande momentum oscillator	Fidelity Investments (2019) and Trading Technologies (2019)
Chandelier exit long	StockCharts (2019)
Chandelier exit short	StockCharts (2019)
Choppiness index	TradingView (2019)
Coppock curve	StockCharts (2019)
Detrended price oscillator	Fidelity Investments (2019) and StockCharts (2019)
	TradingView (2019)
Donchian channel	Cavendish Astrophysics (2011), TradingView (2019)
Double exponential moving average	Trading Technologies (2019)
Double smoothed stochastic	Fidelity Investments (2019)
Ease of movement	StockCharts (2019) and TradingView (2019)
Force index	StockCharts (2019) and TradingView (2019)
Hull moving average	Fidelity Investments (2019)
Kaufman's adaptive moving average	StockCharts (2019)
Linear regression intercept	StockCharts (2019) and Trading Technologies (2019)
	Fidelity Investments (2019)
Linear regression trend line	Fidelity Investments (2019) and Trading Technologies (2019)
MACD histogram	StockCharts (2019)
Mass index	StockCharts (2019)
Raw money flow	Fidelity Investments (2019)
Midpoint	Trading Technologies (2019)
Midprice	Trading Technologies (2019)
Normalized average true range	Trading Technologies (2019)
Standard support 1	Fidelity Investments (2019)
Standard support 2	Fidelity Investments (2019)
Standard resistance 1	Fidelity Investments (2019)
Standard resistance 2	Fidelity Investments (2019)
Fibonacci support 1	Fidelity Investments (2019)
Fibonacci support 2	Fidelity Investments (2019)
Fibonacci resistance 1	Fidelity Investments (2019)
Fibonacci resistance 2	Fidelity Investments (2019)
Demark pivot point	Fidelity Investments (2019)
Demark support	Fidelity Investments (2019)
Demark resistance	Fidelity Investments (2019)
Price channel upper	StockCharts (2019) and Trading Technologies (2019)
Price channel lower	StockCharts (2019) and Trading Technologies (2019)
PPO histogram	StockCharts (2019)
Percentage volume oscillator	StockCharts (2019)
PVO histogram	StockCharts (2019)
Price volume trend	Trading Technologies (2019) and TradingView (2019)
Pring's know sure thing oscillator	StockCharts (2019) and TradingView (2019)
Pring's special K	StockCharts (2019)
Relative vigor index	Fidelity Investments (2019)
Standard error	Fidelity Investments (2019)
Stochastic RSI	Fidelity Investments (2019) and TradingView (2019)
Triple exponential moving average	Trading Technologies (2019)
Triple exponential moving average oscillator	StockCharts (2019) and Trading Technologies (2019)
	TradingView (2019)
True strength index	StockCharts (2019)
Typical price	Fidelity Investments (2019)
Ulcer index	StockCharts (2019)
Ultimate oscillator	StockCharts (2019) and Trading Technologies (2019)
	Fidelity Investments (2019) and TradingView (2019)
Volume oscillator	Fidelity Investments (2019)
Volume price trend	Cavendish Astrophysics (2011)
Volume weighted average price	StockCharts (2019) and Trading Technologies (2019)
	TradingView (2019)
Vortex indicator positive	StockCharts (2019)
Vortex indicator negative	StockCharts (2019)
Welles wilder's smoothing average	Trading Technologies (2019)

Outline

Logistic regression and neural networks

- Logistic regression: $\boldsymbol{y} = \psi(\boldsymbol{X}\boldsymbol{w} + \boldsymbol{b}), \psi(\boldsymbol{x}) = \frac{1}{1+e^{-x}}$
- Artificial neural network (ANN):
$\boldsymbol{Y} = \psi_\ell(...\psi_2(\psi_1(\boldsymbol{X}\boldsymbol{W_1} + \boldsymbol{b_1})\boldsymbol{W_2} + \boldsymbol{b_2})...\boldsymbol{W_\ell} + \boldsymbol{b_\ell})\boldsymbol{w}$

An ANN with one hidden layer is an universal approximator of the space of continuous functions (Universal approximation theorem)

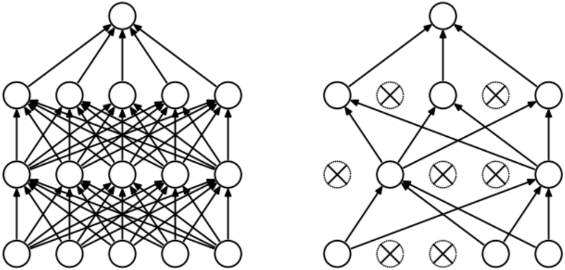
- However, the insertion of additional hidden layers allows to create a **hierarchical representation** of the knowledge

Dropout

Dropout (Srivastava et al., 2014) is a regularization method to avoid overfitting in the ANN training process.

- In each iteration, instead of computing every possible parameter throughout the network in the backpropagation, each neuron is deactivated with a probability p.
  - Exploitation vs exploration (bias-variance dilemma)
- Applications of dropout for financial applications are still scarce (Nazário et al., 2017; Henrique et al., 2019)

Dropout



(a) Standard Neural Net (b) After applying dropout.

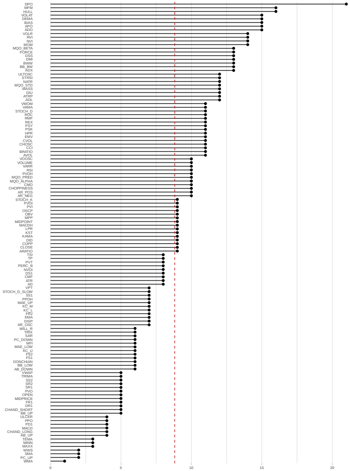
Srivastava et al. (2014)

Outline

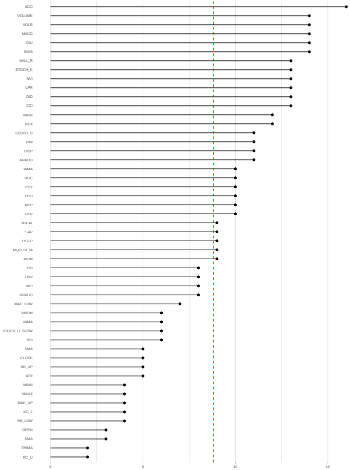
Empirical analysis

- **Data**: Stock prices of firms from 7 markets: United States, United Kingdom, France, Germany, China, Japan and Brazil
- **Feature selection methods**:
    - Sequential Forward Floating Selection: Sequential wrapper method
    - Tournament screening: Heuristic wrapper method
    - LASSO: Embedded method
    - Feature selection was performed for a subset and ANNs were fitted on another
- **Performance evaluation**: Accuracy/Precision/Recall/F1 Score

Selected indicators – Literature + Market



Selected indicators – Only Literature



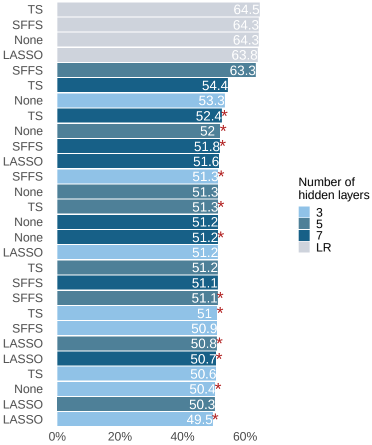
Prediction results

- 40 out of 336 combinations of hyperparameters yielded one class predictions (“only up” or “only down”)
- The emergence of a “strange attractor” (65%) was observed in some combination of hyperparameters for all markets

Out-of-sample prediction results for the S&P 100 Index

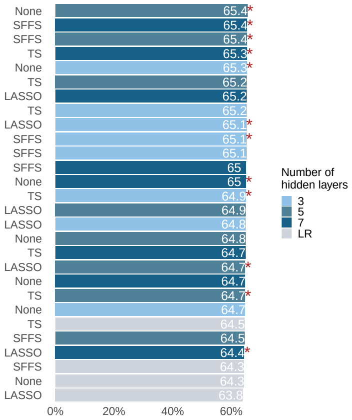
Technical Analysis indicators	Feature selection method	Hidden layers	Dropout	Accuracy	Precision	Recall	F-Score
Literature	LASSO	3	0	0.5128	0.5265	0.6990	0.6006
			0.3	0.5200	0.5268	0.8248	0.6430
		5	0	0.5109	0.5258	0.6783	0.5924
			0.3	0.5181	0.5267	0.7931	0.6330
		7	0	0.5121	0.5253	0.7161	0.6060
			0.3	0.4947	0.5256	0.3669	0.4321
Literature + market	LASSO	3	0	0.6477	0.6577	0.6834	0.6703
			0.3	0.6542	0.6667	0.6804	0.6735
		5	0	0.6497	0.6510	0.7148	0.6814
			0.3	0.6539	0.6588	0.7043	0.6808
		7	0	0.6481	0.6667	0.6567	0.6617
			0.3	0.6513	0.6794	0.6335	0.6557

Prediction results for the S&P 100 Index (Literature)



The * goes for dropout rate of 0.3.

Prediction results for the S&P 100 Index (Literature + Market)



The * goes for dropout rate of 0.3.

Prediction results

Out-of-sample accuracy grouped by target assets and variable sets:

Assets	**Literature**		**Literature + Market**	
	Acc. $\leq 55\%$	Acc. $\geq 60\%$	Acc. $\leq 55\%$	Acc. $\geq 60\%$
United States (S&P 100 Index)	23	5	0	28
United Kingdom (FTSE 100 Index)	28	0	7	21
France (CAC 40 Index)	24	4	3	25
Germany (DAX-30 Index)	28	0	5	23
Japan (Top 50 assets from NIKKEI 225 Index)	24	4	2	26
China (Top 50 assets from SSE 180 Index)	24	4	0	28
Brazil (Bovespa Index)	24	4	0	28

Market efficiency and chaos

- Is the second attractor a reflex of a "follow-up" behavior of the market?
  - Momentum strategies tend to yield a small average return consistently over time (Jegadeesh and Titman, 1993; Swinkels, 2005; Barroso and Santa-Clara, 2015)
- Is there a "regime-switch" at a systematic level?

Profitability of the strategies

- The profitability of the machine learning strategies oscillated between the value of the Buy-and-Hold strategy – some small gains and some big losses
  - Momentum strategies tend to have a high turnover (measure of transaction cost) and yield a large loss in events of crisis or market retraction

Profitability and transaction costs for the S&P 100 Index

Technical Analysis indicators	Feature selection method	Hidden layers	Dropout	Strategy profitability	Number of transactions	TC_0	TC_{BH}
Literature	LASSO	3	0	-26.4434	195	-0.1963	-0.3705
			0.3	-130.7093	1	-130.7092	-160.3766
		5	0	79.8481	89	0.8421	0.5438
			0.3	77.9161	93	0.7701	0.4981
		7	0	-111.1510	89	-1.4438	-1.7723
			0.3	-20.1832	71	-0.1628	-0.9002
Literature + market	LASSO	3	0	61.9372	219	0.2759	0.1193
			0.3	-53.5714	91	-0.6422	-1.0093
		5	0	79.2360	94	0.8422	0.5369
			0.3	65.0487	85	0.8121	0.4136
		7	0	-43.1031	132	-0.3601	-0.5558
			0.3	-31.4264	66	-0.6612	-1.0125
Buy-and-Hold strategy profitability over the out-of-sample period: 31.04701							

Outline

Main conclusions

- The extended "factor zoo" yielded better prediction performance across the markets
- The indicators were not uniformly selected by the feature selection methods
- Out-of-sample accuracy converged to two "attractors": 50% and 65%
- Overall profitability did not outperform the Buy-and-Hold strategy

Recommendations for future studies

- Test for other markets and machine learning models
- Test for other settings of hyperparameters (activation functions, dropout, etc.)
- Test for rolling windows/dynamic models
- Check the temporal consistency of the "second attractor"

Thank you!

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