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Sidnei de Oliveira Cardoso

Implied volatility as a predictor of stock returns: a Brazilian empirical experience

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-graduação em Administração de Empresas of PUC-Rio in partial fulfillment of the requirements for the degree in Mestre em Administração de Empresas.

Advisor: Professor Antônio Carlos Figueiredo Pinto

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Abstract

Cardoso, Sidnei; Pinto, Antonio Carlos Figueiredo (Advisor); **Implied volatility as a predictor of stock returns: a Brazilian empirical experience**. Rio de Janeiro, 2022. 38p. Dissertação de Mestrado – Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

This research first investigates, through regressions, the relationship between the implied volatilities of options and the future returns of 20, 40 and 60 days of the underlying stocks within the Brazilian stock market. These regressions are then subjected to heteroscedasticity tests to ensure that they are not spurious regressions. Finally, we submit the results to robustness tests to confirm the valid regressions and verify the presence of autocorrelation in the series of future returns. The period under analysis is from January 2011 to December 2021, totalling 11 years. Despite having significant regression coefficients, not all of these regressions pass the tests, and one should always exercise caution when using an option implied volatility as a predictor of underlying equity returns in the Brazilian market.

Keywords

implied volatility; Brazilian stock market; zero-cost portfolio; risk-return relationship; option pricing

Resumo

Cardoso, Sidnei; Pinto, Antonio Carlos Figueiredo. **A volatilidade implícita como prognóstico de retorno das ações: uma experiência empírica brasileira.** Rio de Janeiro, 2022. 38p. Dissertação de Mestrado - Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

Esta pesquisa investiga primeiramente, por meio de regressões, a relação entre as volatilidades implícitas das opções e os retornos futuros de 20, 40 e 60 dias das ações subjacentes no mercado acionário brasileiro. Essas regressões são então submetidas a testes de heterocedasticidade para garantir que não são regressões espúrias. Por fim, submetemos os resultados a um teste de robustez que confirma as regressões válidas e verifica a presença de autocorrelação nas séries de retornos futuros. O período analisado é de janeiro de 2011 a dezembro de 2021 em um total de onze anos completos. Apesar de apresentarem coeficientes de regressão significativos, nem todas essas regressões passam pelos testes, e sempre deve-se ter cautela ao usar uma volatilidade implícita de opção como sendo capaz de prever retornos das ações subjacentes no mercado brasileiro.

Palavras-chave

volatilidade implícita; mercado de ações brasileiro; portfólio a custo zero; relacionamento entre risco e retorno; precificação de opções

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1
Introduction

In finance, volatility coincides with the standard deviation of a sample of asset returns. As it is impossible to know today the exact prices of assets in the future, we used to pursue, through statistical and regression methods, estimating the future volatility of corresponding underlying assets. Volatility estimates make it possible to foresee the expectation of future price movements of such assets.

An alternative way for econometric methods to obtain information on an asset's volatility is to analyse the options market. An option premium is a direct function of asset volatility. As the premium is observable, we can obtain its volatility using a pricing model, and the most renowned of them is the Black & Scholes model, consisting of equations seeking to obtain the fair price of options via non-arbitrage arguments. Thus implied volatility is the value of σ that makes the options' theoretical price equal to the market price.

Implied volatility gathers market participants' expectations and a risk premium, with some experts believing that using implied volatility as a predictor of future volatility and returns presents more promising results than models based on historical data. If the financial markets are efficient, then the options implied volatility should contain considerable information about future volatility and returns.

Our focus for this study is on the Brazilian market. Moreover, unlike other studies, our objective is not to determine the best forecast of future volatility but to assess the explanatory power of implied volatilities regarding future returns on specific stocks, mainly the leading stocks of the B3's IBOVESPA index.

The B3 still has no official implied volatility index. However, there is a non-official index developed by the Brazilian Center for Research in Financial Economics at the University of São Paulo (NEFIN) in 2015, the IVol-BR, based on the daily prices of options on the Bovespa B3 index (IBOVESPA) and which measures the expected volatility of the IBOVESPA over the coming two months. Its calculation methodology follows the same as the VIX, the Volatility Index from the Chicago Board Options Exchange (CBOE), with some adjustments

to reflect the Brazilian options market. The IVol-BR calculation procedure is on the NEFIN website (www.nefin.com.br).

The literature on implied volatility is extensive, especially in the United States, since the CBOE was the first to introduce an implied volatility index, the VIX. However, studies on the Brazilian market so far are sporadic. Therefore, this study also aspires to extend the work of (CAINELLI; PINTO; KLÖTZLE, 2020), focusing on individual equities or stocks among the most traded at B3.

This research first investigates, through regressions, the relationship between implied volatilities of options and the future returns of the underlying stocks. These regressions are then subjected to heteroskedasticity tests to ensure they are not spurious regressions. Finally, we submit the results to a robustness test to confirm the valid regressions and verify autocorrelation's presence in the series of future returns.

The results of this study show that the implied volatility does not always help predict the future returns of the underlying stocks in Brazil for the selected stocks. Furthermore, despite displaying significant regression coefficients, not all of these regressions go through the following tests, and caution should always be necessary when using the implied volatility as a predictor of individual equities returns in the Brazilian market.

From this point on, we organised this study in the following way. Chapter 2 includes a theoretical reference. Chapter 3 describes the adopted research methodology. Chapter 4 shows the results of the relationship between implied volatilities and underlying stock returns and the respective tests of heteroskedasticity and robustness. Lastly, Chapter 5 presents the conclusions and suggestions for future research.

2
Theoretical Reference

An option contract's implied volatility (IV) is the value of the volatility of the underlying equity expected for the option's life in annual terms. Furthermore, input into an option pricing model, such as Black–Scholes, should return a theoretical value equal to the option's current market price. An option's implied volatility matches its current market price (given the governing stock price, strike price, time to maturity, risk-free rate and dividend yield). All these values are directly observable except for σ, which measures the market's expectation of the equities' volatility.

This relationship between the market value of stock options and the return of the underlying securities is shown in a study by (SCHMALENSEE; TRIPPI, 1978), with very few American stocks (Avon, IBM, Kodak, MacDonalds, Texas Instruments and Xerox) done from April 29th 1974 through May 23rd 1975. It is important to remember that the Chicago Board Options Exchange (CBOE) started trading options on April 26th 1973, the first options market in the United States. The initial hypothesis they had the most confidence in was that changes in expected volatility should be related to historical security-specific volatility. Using historical volatility to forecast future volatility lies in believing that the past tends to repeat itself. However, the data virtually did not support this hypothesis. The actual volatility over the contract's life explained the observed option valuations better than the historical volatility. These findings suggest that the market's volatility forecasts are more accurate than simple extrapolations of the past, and the authors have not hidden their unexpectedness that historical volatility had not influenced the markets' expectations.

There is an apparent conflict in applying an approach that assumes the asset price has known constant volatility to a situation in which volatility must be forecast because it changes randomly over time (CANINA; FIGLEWSKI, 1993; HULL; WHITE, 1987; WIGGINS, 1987). In addition, stochastic volatility models require the investor to forecast not just a single volatility parameter but the entire joint probability distribution for asset returns and changes in volatility and the market price of volatility risk. These requirements make these models

significantly more challenging to implement than Black-Scholes or any constant-volatility models.

However, although the broadly-collective belief amid finance professionals that implied volatility is a more acceptable projection than historical volatility, research has produced interestingly divergent results about whether implied volatility estimates future volatility or if it does so efficiently. For example, determining that implied volatility is a poor forecast of subsequent realised volatility (CANINA; FIGLEWSKI, 1993) analysed the S&P 100 index option between March 1983 and March 1987, adding that "*implied volatility has virtually no correlation with future volatility and that it has no foreseeable information contained in recently observed volatility*".

(DAY; LEWIS, 1992) examined options on the S&P 100 from 1983 to 1989 and supported the idea that although implied volatility might contain some information about ensuing volatility, it is overtaken by time-series conditional volatility models, such as GARCH and EGARCH, thus indicating that implied volatility is an inefficient estimator of future volatility. (LAMOUREUX; LASTRAPES, 1993), who studied the implied volatilities of 10-stock options traded on the CBOE between 1982 and 1984, also found that the information contained in historical volatility is superior to that contained in implied volatility.

Differently, (FLEMING, 1998) evaluated the performance of the implied volatility of the S&P 100 for the period between 1982 and 1995 (excluding the 1987 crash). The results indicated that the implied volatility contains relevant information about the future volatility, surpassing the historical volatility in the forecast of future returns. (CHRISTENSEN; PRABHALA, 1998), tend to support the idea that implied volatility not only contains essential knowledge about future volatility but is also more predictive than historical volatility. They studied the S&P 100 index options (OEX) market with more extended time series and non-overlapping data covering November 1983 to May 1995. They show that implied volatility is an unbiased and efficient estimator of subsequent returns, and in some circumstances, implied volatility includes the information contained in previously realised volatility. (BLAIR; POON; TAYLOR, 2001) reach similar conclusions but basing their study on higher frequency data, usually intraday values, instead of only weekly or daily quotes. (HANSEN, 1999), analyses the Danish option and equity markets and concludes that implied volatility is a good forecaster of subsequent realised volatility. (CHRISTENSEN; HANSEN, 2002) also confirm the results of (CHRISTENSEN; PRABHALA, 1998) in their study of a more recent period with robustness

checks. They also broadened their study to put options and found that put implied volatility is foretelling. Not as significantly, however, as call implied volatility. A later study of the S&P 500 index and its options by (SHU; ZHANG, 2003) also supports the idea that implied volatility is a superior predictor of future returns and (CORRADO; MILLER, 2005) work brought forth similar conclusions, notably with data after 1995.

From a different perspective, (SZAKMARY; ORS; KIM; DAVIDSON III, 2003) studied thirty-five options markets and found that, for a significant majority of commodities, implied volatility surpasses historical volatility in forecasting the volatility of the underlying prices and their returns. Then, after analysing the S&P/ASX 200 index options traded on the Australian Stock Exchange, (LI; YANG, 2009) also concluded that the implied volatilities of either calls or puts are better than historical volatility at forecasting subsequent returns. Moreover, they find that the volatility implied in call options is a nearly unbiased estimator of future volatility, thus giving credit to the widely shared belief that implied volatility contains some information about future volatility and is superior to historical volatility.

From the perspective of market practitioners, several papers have analysed the VIX1 and VIX futures term structures, trying to infer future movements in the spot VIX and the realised volatility (BUETOW; HENDERSON, 2016; LUO; ZHANG, 2012) as well as in the spot equity index (FASSAS, 2012; FASSAS; PAPADAMOU, 2018). All with varying and sometimes contradicting conclusions regarding the implied volatility ability to predict future returns.

More recent papers have attempted to predict the future shape of the volatility surface, i.e., both the moneyness shape and the term structure. Such was the case of (CHALAMANDARIS; TSEKREKOS, 2011). Nevertheless, the work of (ORNELAS; MAUAD, 2019) is also remarkable in currency exchanges and FOREX trading.

In the Brazilian market, most studies refer to single stock equities because of the low liquidity of options. (GABE; PORTUGAL, 2004), studied Oi Telecomunicações, at the time known as Telemar – Tele Norte Leste Participações (TNLP4), and the results point to implied volatility as a model capable of predicting the next day's volatility with more remarkable ability, despite being biased. However, in predicting future returns, statistical volatility surpassed implied volatility over the option's life and was efficient and unbiased. Also (VICENTE; DE SOUSA GUEDES, 2010) compared the explanatory power of implied and historical volatility concerning future volatility using data from the Petrobras options market (PETR4). The study's conclusion indicates that the implied volatility of OTM options has

shown a more significant correlation with future volatility than historical volatility. The weak explanatory ability of ATM and ITM options reveals that either the volatility premium of these options is high or the market has inefficiencies. No evidence was found, in the period studied (January 2006 - December 2008), that historical volatility has any correlation with future volatility in monthly terms.

(ASTORINO; CHAGUE; GIOVANETTI; SILVA, 2017) proposed an implied volatility index for the Brazilian market, the IVol-BR. Its calculation methodology is the same as the VIX but with some adjustments to correct for the low liquidity of the Brazilian stock options and the diminished number of options exercises. The study also demonstrated that the variance premium and the risk aversion measure could predict future IBOVESPA (the main index for the Brazilian stock market) returns due to regressions. However, the IVol-BR revealed an inadequate predictive capacity for IBOVESPA returns four weeks ahead.

More recently, a research paper by (CAINELLI; PINTO; KLÖTZLE, 2020) sought to determine whether the IVol-BR helps predict future returns on the IBOVESPA. They analysed the relationship between the IVol-BR and the future returns of the IBOVESPA in different periods of the Brazilian market through regressions. The study demonstrated that IVol-BR could help forecast future returns at 20, 60, 120 and 250 days, even though the mixed effect of IVol-BR on low levels of future returns and the non-effect of IVol-BR on future returns when at high and low levels of volatility.

3
Methodology

Following the research trajectory by (GIOT, 2005), (BANERJEE; DORAN; PETERSON, 2007), and (RUBBANIY; ASMEROM; RIZVI, 2014), this study focuses on several stocks that are part of the IBOVESPA index in the Brazilian stock market. Thus, this analysis intends to extend the (CAINELLI; PINTO; KLÖTZLE, 2020) survey examining the relationship between the implied volatility of options and future returns of corresponding underlying assets instead of studying indexes and industry sectors.

This study investigates the predictive capacity of implied volatilities generated from call at-the-money (ATM) options. Consistent with (RUBBANIY; ASMEROM; RIZVI, 2014) and (CAINELLI; PINTO; KLÖTZLE, 2020) suggestions that the implied volatility relationship with returns in less than 20 business days is not significant, this study aims to obtain results for the different stocks at horizons of 20, 40 and 60 business days. They are approximately the equivalent of one, two and three consecutive months.

3.1.
Data

The equities sample consists of weekly series downloaded from historical quotes at Brazilian B3 (*São Paulo Stock Exchange B3*), formerly known as Bovespa, from January 2011 to December 2021, as shown in Table 1. Furthermore, to calculate the implied volatility, the options are at-the-money (ATM) next-to-expire, usually with a lifetime ranging from 37 days until seven days to maturity, all American calls, as these are the most liquid in the Brazilian market.

Company Name	Trading Code	Industry Classification
B3	B3SA3	Financial/ Diversified Financial Services
Banco do Brasil	BBAS3	Financial/ Banks
Bradesco	BBDC4	Financial/ Banks
Gerdau	GGBR4	Basic Materials/ Steel and Metallurgy
Itau Unibanco	ITUB4	Financial/ Banks
Petrobras	PETR4	Oil Gas and Biofuels/ Exploration, Refining and Distribution
Usiminas	USIM5	Basic Materials/ Steel and Metallurgy
Vale	VALE3	Basic Materials/ Mining

Table 1 – B3 Company Codes and their Industry Classification.
Source: Own elaboration.

The Black-Scholes model of European option pricing derived the implied volatilities. Although the calls traded on the Brazilian B3 are considered American calls, they are protected against earnings because there is a discount on the identical amounts received as such from the options' exercise prices. Therefore, there are no advantages to exercising early, and they have all the characteristics of European options (HULL, 2017).

The prices of both options and underlying assets are the values traded at the close of trading. Each year considered has the equivalent of 252 business days, and the risk-free interest rate proxy is the annual interest rate of the Interbank Deposit Certificates (CDI), also obtained from the Brazilian B3 website.

The services company IT Evolution provides all other prices, mainly the adjusted quotations (www.itevolution.com.br).

3.2. Data Treatment

After determining the options' implied volatility, we evaluate the series of future returns of 20, 40 and 60 business days of the underlying stocks, following the methodology in the (GIOT, 2005) study. Equation (1) exemplifies the calculus for future stock returns.

$$R_{t+n} = \ln(S_{t+n}) - \ln(S_t) \quad (1)$$

where:

R_{t+n} is the return of the underlying stock at time t + n;

S_{t+n} is the value of the underlying stock at time t + n;

S_t is the value of the underlying stock at time t; and

n = 20 for future returns of 20 business days (~ one month), n = 40 for future returns of 40 business days (~ two months) and n = 60 for future returns of 60 business days (~ three months).

The relationship between option implied volatilities and future returns of the underlying stocks are then analysed using the least-squares regression method, as seen in equation (2):

$$R_{t+n} = \alpha + \beta(IV_t) + \varepsilon_t \quad (2)$$

where:

R_{t+n} is the return of the underlying stock at time t + n;

α is the intercept;

IV_t is the option implied volatility at time t;

β is the slope of the regression line, which captures the impact of the implied volatility in the underlying stock future return; and

ε_t is the residual, or error term, at time t.

3.3. Testing for Heteroskedasticity

A fundamental assumption in least squares linear regression is the homogeneity of the variances $V(\varepsilon_j) = \sigma^2$ for all j, also known as homoskedasticity. After getting the returns on the underlying stocks, we tested them with the (BREUSCH; PAGAN, 1979) and the White (WHITE, 1980) tests to verify that when there is homoskedasticity, there is a constant σ throughout the sample. Conversely, heteroskedasticity is the absence of homoskedasticity.

3.4. Testing for Autocorrelation

We also apply a robustness test to the results obtained, verifying autocorrelation for each regression (20, 40 and 60 working days). In this case, we verify whether autocorrelation exists in the future return series through autoregressive models. We applied the Newey-West tests (NEWEY; WEST, 1987) and the Breusch-Godfrey tests (BREUSCH, 1978; GODFREY, 1978) and tested for 5, 20 and 60 days as regressive periods.

4
Results

Table 2 presents the results of ordinary least squares regressions on the relationship between call options implied volatility and future returns on all underlying stocks shown in Table 1 for 20, 40 and 60 business days. The regressions results indicate a positive and significant relationship between the future returns and implied volatility during the analysed period. We can also observe that the regression coefficients for the 60-day future returns were the most expressive. The regressions results in Table 2 reveal a significant relationship between the stock sample's 20, 40 and 60-day future returns and the implied volatility of the corresponding call options.

Company	Coefficients and R-Square	Future Returns 20 days	40 days	60 days
	intercept α	-0,026**	-0,061***	-0,090***
	intercept p-value	0,042	0,001	0,000
B3 - B3SA3	β	0,131***	0,300***	0,445***
	β p-value	0,003	0,000	0,000
	R Square	0,016	0,039	0,060
	intercept α	-0,026*	-0,039*	-0,075***
	intercept p-value	0,078	0,060	0,002
Banco do Brasil - BBAS3	β	0,097**	0,159**	0,295***
	β p-value	0,028	0,012	0,000
	R Square	0,008	0,011	0,028
	intercept α	-0,027**	-0,038**	-0,076***
	intercept p-value	0,022	0,021	0,000
Bradesco - BBDC4	β	0,125***	0,195***	0,360***
	β p-value	0,003	0,001	0,000
	R Square	0,016	0,019	0,045
	intercept α	-0,067***	-0,140***	-0,209***
	intercept p-value	0,000	0,000	0,000
Gerdau - GGBR4	β	0,202***	0,418***	0,625***
	β p-value	0,000	0,000	0,000
	R Square	0,038	0,074	0,113
	intercept α	-0,018	-0,037**	-0,068***
	intercept p-value	0,142	0,032	0,001
Itau Unibanco - ITUB4	β	0,098**	0,203***	0,352***
	β p-value	0,035	0,002	0,000
	R Square	0,008	0,017	0,037
	intercept α	-0,028*	-0,057**	-0,081***
	intercept p-value	0,074	0,011	0,002
Petrobras - PETR4	β	0,090**	0,183***	0,263***
	β p-value	0,028	0,002	0,000
	R Square	0,008	0,017	0,024
	intercept α	-0,054***	-0,139***	-0,250***
	intercept p-value	0,010	0,000	0,000
Usiminas - USIM5	β	0,122***	0,314***	0,561***
	β p-value	0,006	0,000	0,000
	R Square	0,013	0,039	0,083
	intercept α	-0,037***	-0,071***	-0,109***
	intercept p-value	0,007	0,000	0,000
Vale - VALE3	β	0,144***	0,283***	0,435***
	β p-value	0,001	0,000	0,000
	R Square	0,019	0,038	0,061

Table 2 - Regressions between future stock returns and call option implied volatility.
Source: Own elaboration. * significance at 10%; ** significance at 5%; *** significance at 1%.

Another thing to look at is that the absolute values of the regressions coefficients between the implied volatility of the 60-day future returns are all higher than the coefficients of the other regressions in Table 2.

These regression analyses aim to describe the relationship between two variables based on the data from the sample and to predict the dependent variable's value, the 20, 40 or 60-day returns, based on the implied volatility values. However, even though we can make such predictions based on the regressions above, this does not indicate that we can assert any causal relationship between the call option implied volatility and the 20, 40 or 60-day returns. Hence, to confirm this causality, one has to fulfil some further hypotheses testing. As a consequence, then, we use the Breusch-Pagan and the White Test to verify if there is heteroskedasticity, where our null hypothesis for these tests is:

H_0: *the regression line captures the relationship between variables because the variance is homogeneous throughout the residuals*.

The hypothesis above is acceptable when the p-value of the tests is 0,05 or above, confirming that variances of the residuals ε_i of the regressions are homogeneous, as shown in Table 3.

Company	Heteroskedasticity Testing	Future Returns 20 days	40 days	60 days
	Breusch-Pagan LM stat	3,523	17,413	32,732
	f-stat	3,532	17,895	34,591
B3 - B3SA3	p-value	**0,061**	0,000	0,000
	White Test f-stat	1,778	10,041	17,612
	p-value	**0,170**	0,000	0,000
	Breusch-Pagan LM stat	8,205	8,318	7,016
	f-stat	8,295	8,411	7,078
Banco do Brasil - BBAS3	p-value	0,004	0,004	0,008
	White Test f-stat	4,619	4,587	4,425
	p-value	0,010	0,011	0,012
	Breusch-Pagan LM stat	3,333	1,029	0,176
	f-stat	3,340	1,027	0,175
Bradesco - BBDC4	p-value	**0,068**	**0,311**	**0,675**
	White Test f-stat	2,729	0,589	0,091
	p-value	**0,066**	**0,555**	**0,913**
	Breusch-Pagan LM stat	24,390	29,886	14,275
	f-stat	25,384	31,418	14,588
Gerdau - GGBR4	p-value	0,000	0,000	0,000
	White Test f-stat	13,312	17,003	9,344
	p-value	0,000	0,000	0,000
	Breusch-Pagan LM stat	1,671	0,476	0,459
	f-stat	1,670	0,475	0,458
Itau Unibanco - ITUB4	p-value	**0,197**	**0,491**	**0,499**
	White Test f-stat	0,989	0,290	0,245
	p-value	**0,373**	**0,748**	**0,783**
	Breusch-Pagan LM stat	18,281	46,637	56,649
	f-stat	18,817	50,585	62,633
Petrobras - PETR4	p-value	0,000	0,000	0,000
	White Test f-stat	9,803	26,429	32,862
	p-value	0,000	0,000	0,000
	Breusch-Pagan LM stat	43,482	44,228	17,453
	f-stat	46,881	47,754	17,938
Usiminas - USIM5	p-value	0,000	0,000	0,000
	White Test f-stat	28,719	27,649	11,654
	p-value	0,000	0,000	0,000
	Breusch-Pagan LM stat	47,805	50,892	37,698
	f-stat	51,966	55,649	40,208
Vale - VALE3	p-value	0,000	0,000	0,000
	White Test f-stat	27,723	32,803	27,071
	p-value	0,000	0,000	0,000

Table 3 - Heteroskedasticity testing. All regressions where the variances of the residuals are homogeneous throughout the samples have p-values = 0,05 or above and are in bold type, thus considered homoscedastic. All others with a p-value of less than 0,05 are considered heteroskedastic. Source: Own elaboration.

The responses of the two tests (Breusch-Pagan and White Test) in Table 3 agreed in all regressions tested. There was no regression where one test showed it to be homoscedastic and the other to be heteroscedastic for the same regression. Furthermore, Table 4 shows the regressions that have not presented issues regarding heteroscedasticity.

Company	Heteroskedasticity Testing	Future Returns		
		20 days	40 days	60 days
B3 - B3SA3	Breusch-Pagan LM stat	3,523		
	f-stat	3,532		
	p-value	**0,061**		
	White Test f-stat	1,778		
	p-value	**0,170**		
Bradesco - BBDC4	Breusch-Pagan LM stat	3,333	1,029	0,176
	f-stat	3,340	1,027	0,175
	p-value	**0,068**	**0,311**	**0,675**
	White Test f-stat	2,729	0,589	0,091
	p-value	**0,066**	**0,555**	**0,913**
Itau Unibanco - ITUB4	Breusch-Pagan LM stat	1,671	0,476	0,459
	f-stat	1,670	0,475	0,458
	p-value	**0,197**	**0,491**	**0,499**
	White Test f-stat	0,989	0,290	0,245
	p-value	**0,373**	**0,748**	**0,783**

Table 4 - Regressions with the significative relationship between the implied volatility and future returns and homoscedastic, i.e. the variance of the residuals are also homogeneous throughout the samples.
Source: Own elaboration.

The following testing sequence is the autocorrelation where we apply Newey-West and Breusch-Godfrey tests for all regressions shown in Table 4. For these tests, the hypothesis is that if the p-value is smaller than 0,05, the regression indicates significant autocorrelation for each regression tested against 5, 20 and 60 lagging working days. The results are in different tables, one for each company. When there is any discrepancy between the two tests, we add a new independent variable, the corresponding dependent variable, which lagged in one week (5 business days), trying to overcome the autocorrelation problem.

The results in Table 5 present the autocorrelation tests for the company B3 B3SA3 regressions. In this case, there was a discrepancy between the two tests since the Breusch-Godfrey tests indicated autocorrelation with p-values lower than 0,05 for the three lagged

periods (5, 20 and 60 days), while the Newey-West tests with p-values above 0,05 indicated absence of autocorrelation.

B3 B3SA3 Autocorrelation				With added independent variable		
20-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	**0,574**	0,000	0,000
LM p-value	0,000	0,000	0,000	**0,573**	0,000	0,000
Newey-West p-value	**0,143**	**0,237**	**0,254**	**0,561**	**0,540**	**0,430**

Table 5 - Autocorrelation tests for B3 B3SA3 equity regression where p-values lower than 0,05 indicate significant autocorrelation for the 20 working days regression against 5, 20 and 60 lagging working days. P-values in bold indicate that there is not a significant autocorrelation.
Source: Own elaboration.

Adding an independent variable in the tests, the 20-day regression with a lag of one week (5 working days), both tests agree with the absence of autocorrelation for the 5-day lag. However, the tests with the other lags (20 and 60 working days) kept the discrepancy between the tests. Nevertheless, at least one of the tests cleared this regression from autocorrelation – the Newey-West test.

The B3 – Brasil Bolsa Balcão B3SA3 20-day returns regression is in Figure 1.

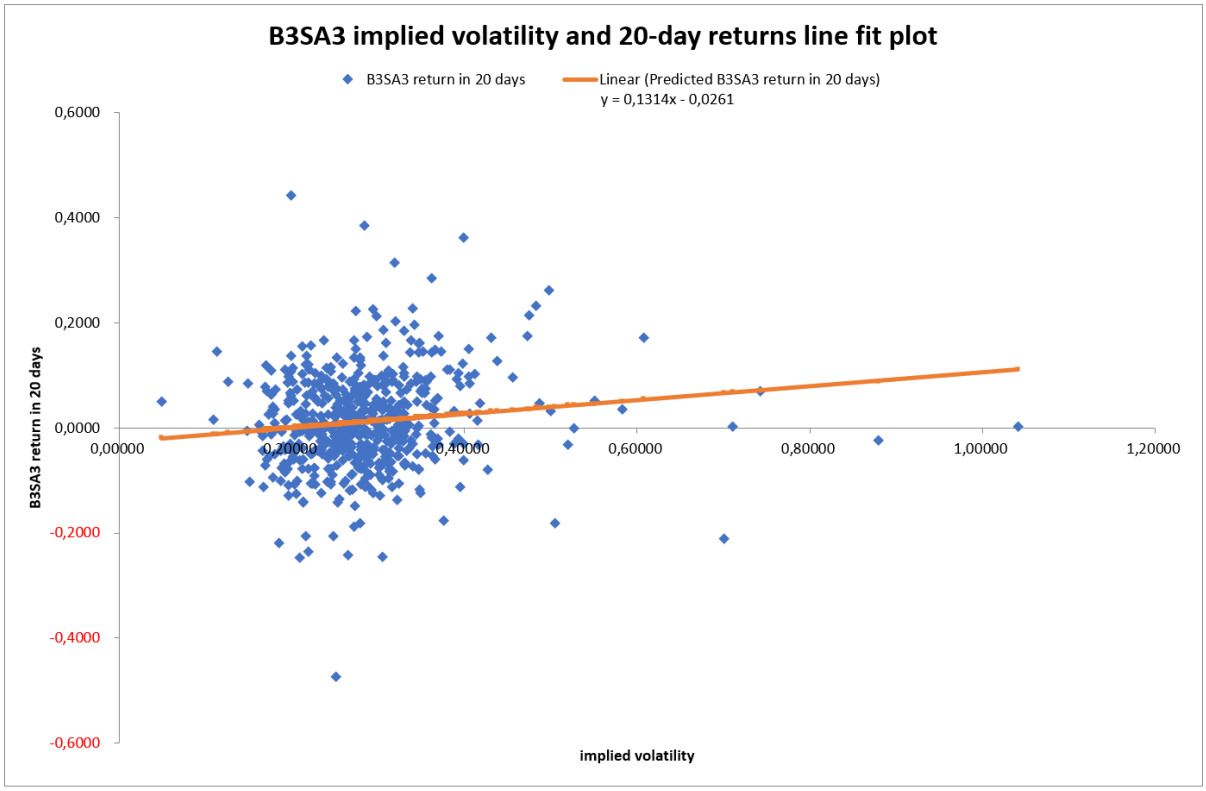

Figure 1 - B3 B3SA3 regression between implied volatility and 20-day returns.
Source: Own elaboration.

The autocorrelation tests for Bradesco BBDC4 in Table 6 also show some agreement between the Breusch-Godfrey results and the Newey-West tests, especially when both indicate autocorrelation.

Bradesco BBDC4 Autocorrelation				With added independent variable		
20-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	0,000	0,000	0,000
LM p-value	0,000	0,000	0,000	0,000	0,000	0,000
Newey-West p-value	0,039	**0,079**	**0,051**	**0,193**	**0,193**	**0,107**
40-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	0,000	0,000	0,000
LM p-value	0,000	0,000	0,000	0,000	0,000	0,000
Newey-West p-value	**0,112**	**0,194**	**0,137**	**0,207**	**0,259**	**0,189**
60-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	**0,200**	0,004	0,000
LM p-value	0,000	0,000	0,000	**0,198**	0,004	0,000
Newey-West p-value	0,001	0,010	0,016	0,000	0,000	0,000

Table 6 - Autocorrelation tests for Bradesco BBDC4 equity regressions where p-values lower than 0,05 indicate significant autocorrelation for each regression (20, 40 and 60 working day returns) against 5, 20 and 60 lagging working days. P-values in bold indicate that there is not a significant autocorrelation.
Source: Own elaboration.

The results of the two tests imply a strong autocorrelation in the 20-day returns regression when lagged by one week (5 working days). However, for the other lags, the tests conflict with each other. This conflict extends to the 40-day returns for all lags.

The tests also indicate autocorrelation for all lags (5, 20 and 60 working days) in the 60-day regressions.

All other regressions indicate a conflict between the two tests, Breusch-Godfrey and Newey-West, thus requiring further effort, which is done by adding an independent variable and redoing the tests – and at the right of Table 6, we have the results: the 20 and 60-day regressions, both with a 5-day lag now indicate a conflict between the two tests. So the improvement, in this case, was that the 20-day regression now has at least one test indicating the absence of autocorrelation for all lags. The 20-day regression is in Figure 2.

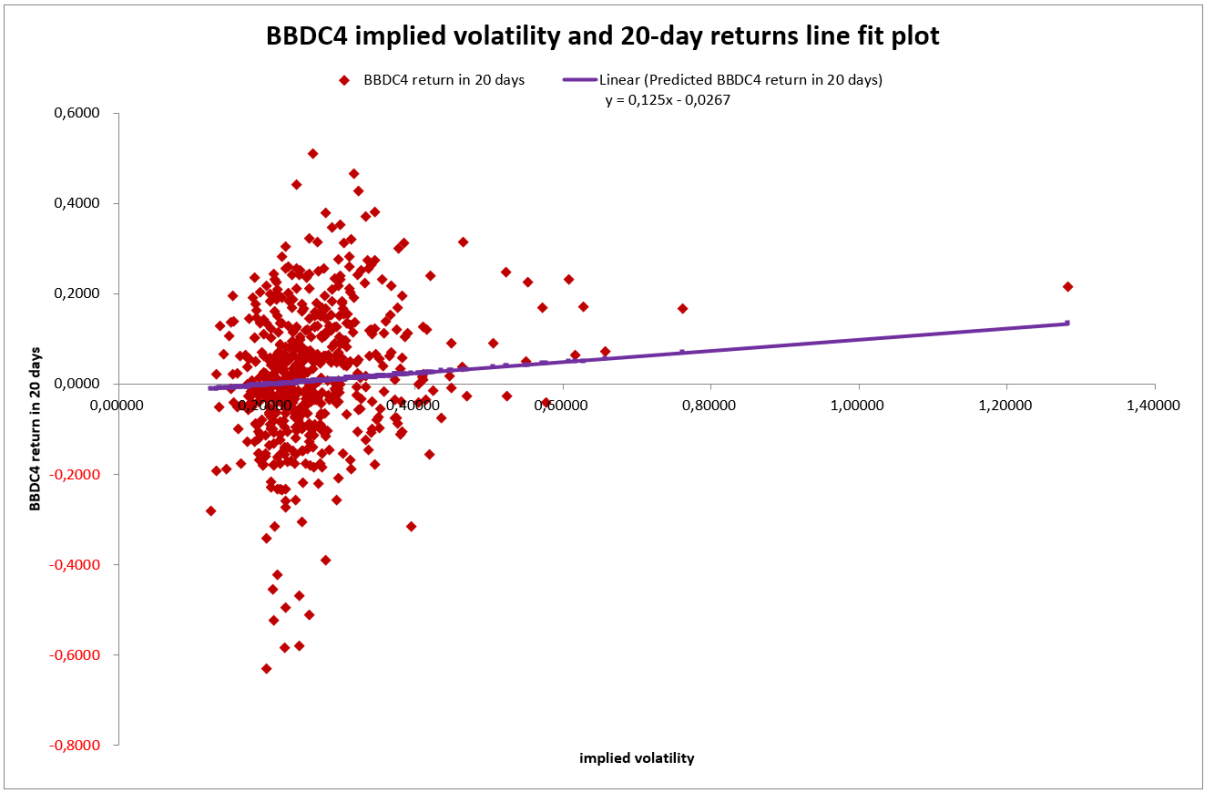

Figure 2 - Bradesco BBDC4 regression between implied volatility and 20-day returns.
Source: Own elaboration.

The 40-day returns regression also indicates a conflict between the two tests, Breusch-Godfrey and Newey-West, and even adding an independent variable could not improve the autocorrelations for the Breusch-Godfrey tests. Only the Newey-West cleared them from autocorrelation for all lags, and the regression is in Figure 3.

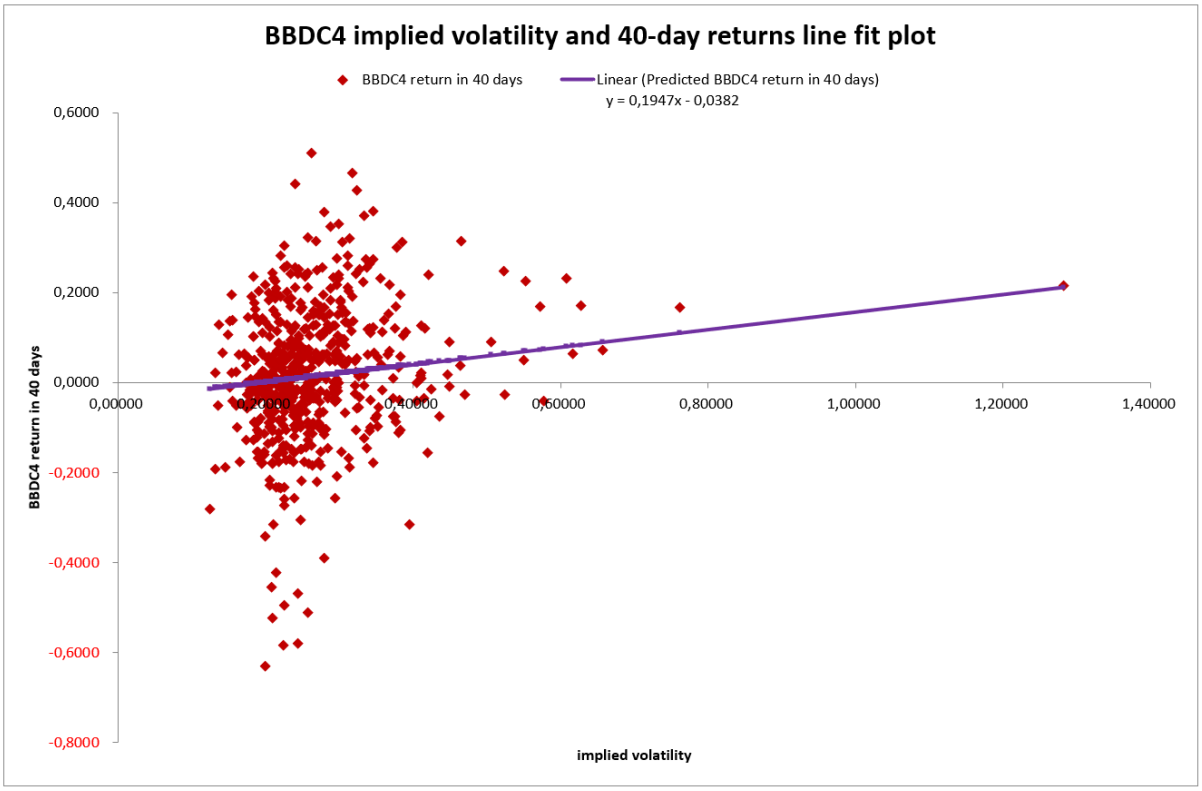

Figure 3 - Bradesco BBDC4 regression between implied volatility and 40-day returns.
Source: Own elaboration

The autocorrelation tests for Itau Unibanco shown in Table 7 indicate a conflict between Breusch-Godfrey and Newey-West tests. They do not agree with all regressions and lags, except for the 60-day returns with a 5-day lag.

Itau Unibanco ITUB4 Autocorrelation				With added independent variable		
20-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	0,000	0,000	0,000
LM p-value	0,000	0,000	0,000	0,000	0,000	0,000
Newey-West p-value	**0,200**	**0,286**	**0,272**	**0,542**	**0,588**	**0,549**
40-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	0,000	0,000	0,000
LM p-value	0,000	0,000	0,000	0,000	0,000	0,000
Newey-West p-value	**0,095**	**0,199**	**0,213**	**0,184**	**0,224**	**0,153**
60-day returns						
Lag in days	**5**	**20**	**60**	**5**	**20**	**60**
Breusch-Godfrey						
LM* p-value	0,000	0,000	0,000	**0,159**	0,000	0,000
LM p-value	0,000	0,000	0,000	**0,157**	0,000	0,000
Newey-West p-value	0,008	**0,051**	**0,112**	0,000	0,001	0,001

Table 7 - Autocorrelation tests for Itau Unibanco ITUB4 equity regressions where p-values lower than 0,05 indicate significant autocorrelation for each regression (20, 40 and 60 working day returns) against 5, 20 and 60 lagging working days. P-values in bold indicate that there is not a significant autocorrelation.
Source: Own development.

Adding an independent variable showed no improvement for the 20 and 40-day returns regressions and neither for the 60-day regression. For the latter, the indication of autocorrelation only swapped between the tests, thus maintaining the conflict.

At least one of the tests indicated the absence of autocorrelation for the 20-day returns regression in all lags, and the regression is in Figure 4.

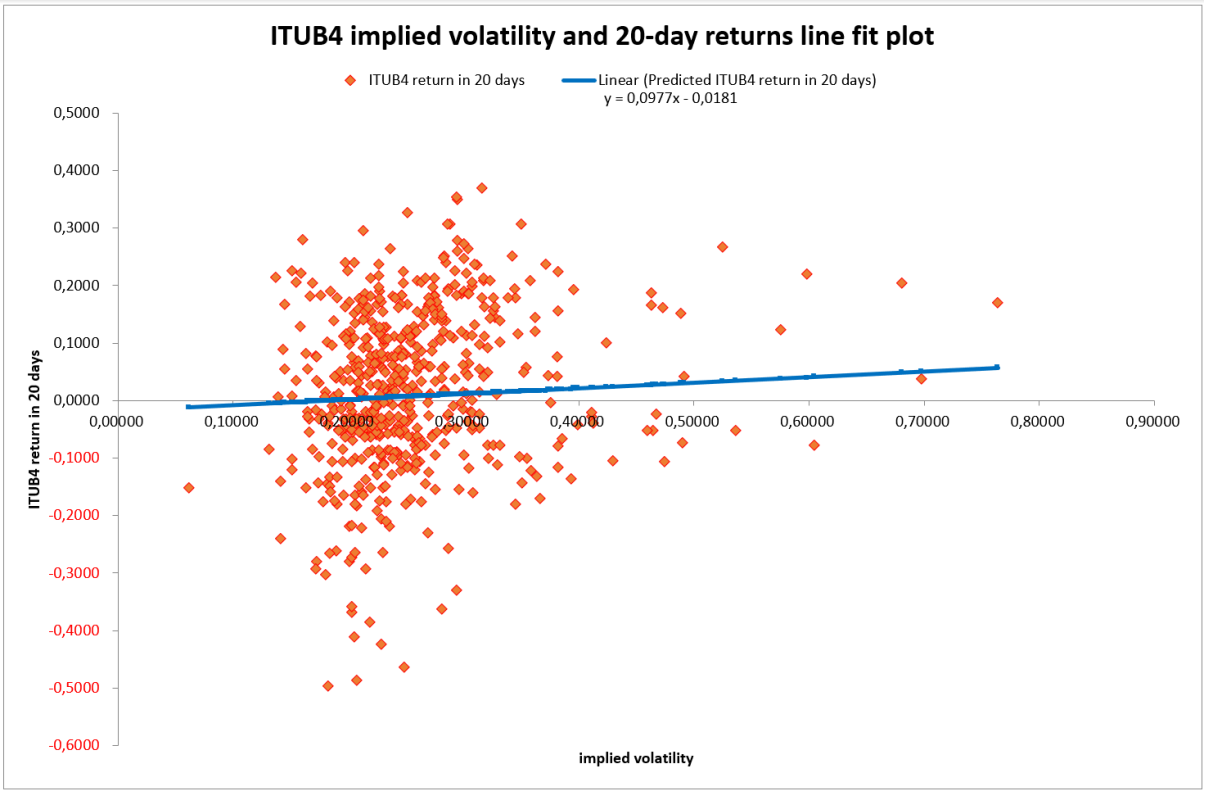

Figure 4 - Itau Unibanco ITUB4 regression between implied volatility and 20-day returns.
Source: Own development.

Also, the same occurred with the 40-day returns regression, at least one of the tests indicated the absence of autocorrelation for all lags, and the regression is in Figure 5.

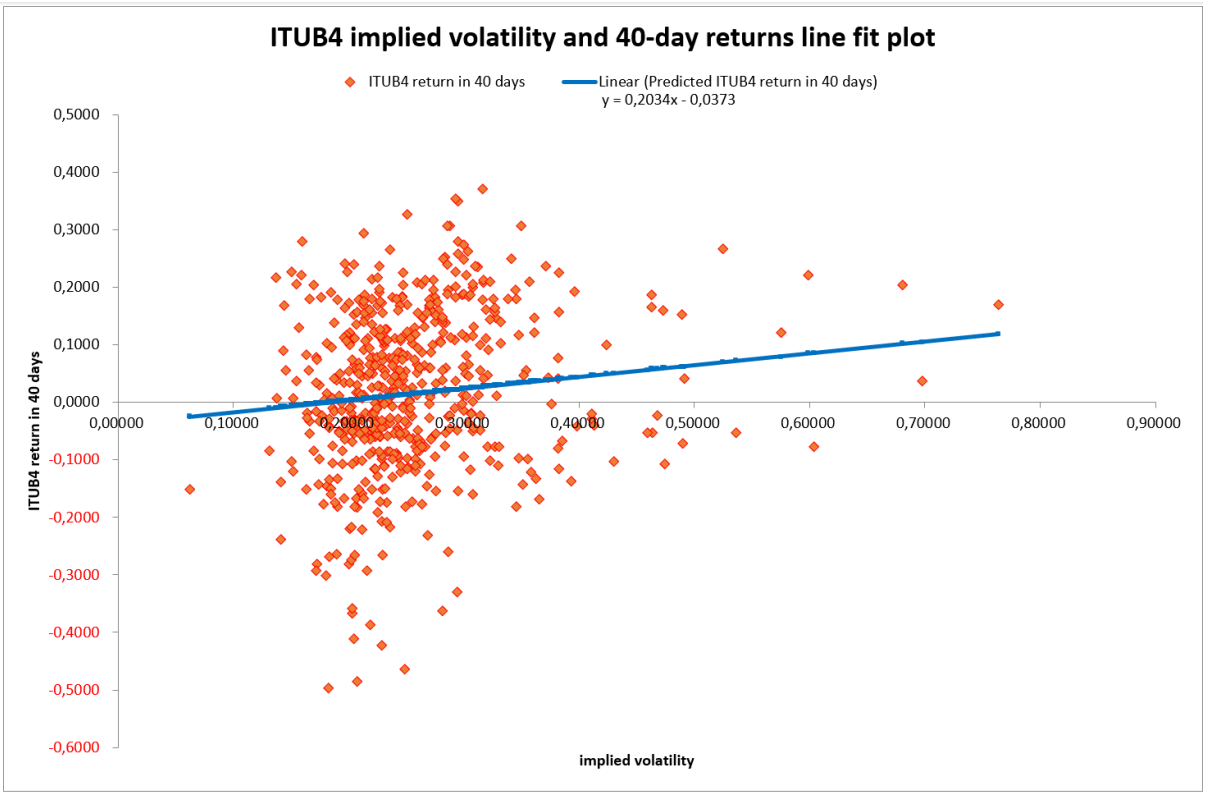

Figure 5 - Itau Unibanco ITUB4 regression between implied volatility and 40-day returns. Source: Own development.

5
Conclusion

This study aimed to determine whether the implied volatility of call options of the leading shares of the IBOVESPA index help predict future returns for 20, 40 and 60 business days. They are approximately the equivalent of one, two and three consecutive months. The equities analysed in this study are those shown in Table 1: B3, Banco do Brasil, Bradesco, Gerdau, Itau Unibanco, Petrobras, Usiminas and Vale.

Through OLS regressions, we initially analysed the relationship between the implied volatilities and the future returns of their respective underlying stocks at horizons of 20, 40 and 60 business days.

The regressions results indicate a positive and significant relationship between the future returns and implied volatility. The 60-day future returns regressions were the most expressive, with significance equal to or below 5% throughout all coefficients. The regression results reveal a significant relationship between the stock sample's 20, 40 and 60-day future returns and the implied volatility of the corresponding call options.

Next, we tested the possibility that the regressions were spurious through the homoscedasticity tests verifying if the variance of the residuals for each regression is homogeneous.

The findings indicated that all the Bradesco regressions, the 20-day regression of B3, and all (20-day, 40-day, and 60-day) regressions of Itau Unibanco could be considered homoscedastic. Therefore, we attempted to correct the heteroscedastic problems for the other regressions by replacing the independent variable with its natural logarithm and rerunning the tests. Still, the results remained unchanged, meaning it is not wise to consider all the other regressions homoscedastic except for the regressions mentioned above.

Finally, after this filtering, we also applied two robustness tests (Breusch-Godfrey and Newey-West) to the remaining results, verifying autocorrelation for each regression and testing them for lags of 5, 20 and 60 days as regressive periods. When there was any discrepancy

between the two tests, we included a new independent variable, the corresponding dependent variable lagging in one week (5 business days), to reduce the autocorrelation issues.

Both tests indicated autocorrelation issues within the Bradesco and Itau Unibanco regressions for 60-day returns. Nevertheless, only the Newey-West test indicated the absence of autocorrelation for the remaining regressions, suggesting that we must observe due caution to explore the results.

Outcomes of B3 (20-day), Bradesco(20 and 40day) and Itau Unibanco (20 and 40-day) regressions returns are consistent with previous studies such as (CAINELLI; PINTO; KLÖTZLE, 2020). However, some heteroskedastic and autocorrelated findings make it more challenging to draw a general conclusion. In addition, several reasons may explain the differences between the studies, such as options liquidity, the aggregate predictive power of an index and the diversity of firms listed at IBOVESPA. It should serve as another prudence warning because B3, Bradesco and Itau Unibanco are from a single economic segment, the Finance Sector.

When studying individual stocks for the Brazilian stock market, it may be necessary to consider other factors in predicting future returns. Therefore, for future studies, it is recommended to search and include other variables that can help the implied volatility in the predictability of future stock returns. Another possible extension of this study is the adoption of other more sophisticated econometric methods, for example, more elaborate autoregressive models, to analyse the effects of implied volatility on stock returns.

6
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