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Skewness and Kurtosis as Pricing Mechanism for the Political Risk Premium in FTSE 100 Index Options

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Abstract

Is there a political risk premium found in option prices, and is it priced through non-normal expected return distributions? This paper examines if non-normal skewness and kurtosis are responsible for pricing the political risk premium in options. Using a long-term sample of FTSE 100 option prices, theoretical Black-Scholes option prices are compared to skewness and kurtosis adjusted prices under varying levels of political uncertainty. The main conclusion of this paper states that non-normality is, at least in part, responsible for pricing in the political risk premium. When option markets have more negatively skewed or leptokurtic expected returns, political uncertainty is move volatile and takes more extreme values. Under high political uncertainty, it is possible to achieve statistically and economically significant improved option price estimates by adjusting for skewness and kurtosis in expected return distributions.

Keywords: political risk premium, options, skewness, kurtosis, non-normality, FTSE 100, Gram-Charlier expansion, Black-Scholes

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Introduction

Is non-normality in expected return distributions responsible for the pricing of a political risk premium in options? In this paper, the pricing of the political uncertainty risk premium in FTSE 100 index options through implied volatility, skewness, and kurtosis will be analyzed. The presence of a political risk premium in asset prices is generally accepted. However, there seems to be a debate on to what extent, but also primarily how the political risk premium is priced into options. Gaining a better understanding of this mechanism is important for two reasons. First, knowledge of the pricing of political uncertainty can help us understand the market's perception of outcomes of uncertain political events. Second, understanding how risk embedded in option prices is priced can provide tools necessary for predictive and normative pricing models used in options trading.

Existing literature on option pricing biases focusses on explaining the so-called volatility smile. This phenomenon relates to the structural difference between theoretical option prices, as determined by the well-known Black-Scholes option pricing formula and observed prices. A fundamental assumption of this model is the lognormal distribution of asset price returns. Although convenient to work with, this assumption becomes rather inconvenient when faced with a reality in which returns follow a non-normal distribution. Asset price returns tend toward distributions with negative skewness and kurtosis higher than three, whereas normal distributions have zero skewness and kurtosis of three (Rachev et al., 2005).

Intuitively, periods of high political uncertainty are especially prone to non-normal return distributions. During elections periods or menacing trade wars, one party can win or lose, or the trade issue is resolved or escalates. Under these circumstances, the return distribution is better approximated by a binomial distribution, which becomes more fat-tailed and negatively skewed during periods of political uncertainty (Jackwerth, 1999). This paper shows that by extending the Black-Scholes option pricing model to include non-normal values of skewness and kurtosis, it is possible to capture the pricing mechanism that translates the political uncertainty premium into option prices.

In theory, if markets value options different under non-normal expected returns, the theoretical deviation from the Black-Scholes option price should be more significant when expected returns have a higher deviation from normality. By inferring expected return distributions from observed option prices and relating these to political uncertainty, it is possible to test if non-normality plays a role in pricing political uncertainty in options.

This paper builds upon the work of Corrado and Su (1996) & (1997), who adjusted the Black-Scholes option pricing model to reflect possible levels of non-normal skewness and kurtosis. Corrado and Su show that the volatility smile is the result of negative skewness and excess kurtosis. The pricing bias generated by the Black-Scholes model, observed at deep in- or out-of-the-money options disappears using the for skewness and kurtosis adjusted expected return distributions. The work of Corrado and Su is extended using the second building block: Kelly, Pastor, & Veronesi (2016). Kelly et al. show that political uncertainty increases the value of options that protect against adverse political shocks.

Using daily options price data of FTSE 100 index options ranging from 2005 to 2020 collected from Datastream, daily implied volatility, skewness, and kurtosis levels are inferred. Using these values, next-day out-of-sample option prices are estimated using both the traditional Black-Scholes and the for higher skewness and kurtosis adjusted pricing model. The adjusted pricing model is based on the approach proposed by Corrado and Su (1997) and uses a Gram-Charlier expansion to adapt the Black-Scholes model. In order to match the implied return expectations and their corresponding option prices to the level of political uncertainty, data from the daily Economic Political Uncertainty Index has been used. The index is developed by Baker et al. (2016) and is composed based on newspaper presence of terms related to economic uncertainty.

A three-step approach is used to test the pricing of political uncertainty through non-normality. First, the theoretical Black-Scholes mispricing is regressed on the measure of political uncertainty. If non-normality plays a role in the pricing of the political risk premium, observed option prices should deviate more from theoretical Black-Scholes prices when political uncertainty is high.

The second step will look into the relationship between inferred skewness and kurtosis levels and political uncertainty. If non-normality is related to political uncertainty, the determinants of non-normality, skewness, and kurtosis, should also be related to political uncertainty. Because the volatility of daily political uncertainty turns out to be higher during periods of high political uncertainty, a GARCH(1,1) model is used to model the time-varying variance separately. The resulting time-series model examines the relations between the mean level of political uncertainty, the first and second difference of political uncertainty, and daily levels of skewness and kurtosis.

In the final step, both pricing models will be directly compared by regressing the difference between the mispricing of the Black-Scholes model and the skewness and kurtosis adjusted model on daily political uncertainty. If there is mispricing due to political uncertainty, and there is a relation between political uncertainty and the levels of skewness and kurtosis, it can be hypothesized that the decrease in option mispricing after controlling for skewness and kurtosis is larger when uncertainty is higher.

The main result indicates that price deviations from theoretical Black-Sholes prices are larger during periods of high uncertainty. When political uncertainty is low, the Black-Scholes model has a mispricing bias of underpricing in-the-money call options and overpricing out-of-the-money call options. This pattern corresponds with the Black-Scholes pricing bias, as documented in previous studies by MacBeth and Mervillie (1979). In this paper, the Black-Scholes mispricing bias is shown to enlarge under higher political uncertainty.

When the level of political uncertainty is at the 10% lowest values, a 20% in-the-money call options in underpriced by 0.78%, or £9.76. When political uncertainty increases to the 10% highest value, the Black-Scholes model underprices a 20% in-the-money call option by 1.24%, or £15.19, corresponding to a 55.73%, or £5.44 increase in mispricing. The effect is less pronounced for at- and out-of-the-money call options. The incremental effect of a similar change in political uncertainty on a 20% out-of-the-money call option is a £2.74 increase in the overpricing of the option contract. Meanwhile, an at-the-money option is underpriced 26 pence less under the same change in political uncertainty.

The results on Black-Scholes option mispricing correspond with previous findings by Kelly et al., (2016), who find that political uncertainty increases the value of the out-of-the-money put option. Although this research does not analyze put options, put-call parity can be used to relate the findings from call options. As in-the-money call options correspond to out-of-the-money put options, the finding provides evidence that investors are willing to pay a premium for options that provide protection against the tail risk associated with political uncertainty and negatively skewed expected returns. Moreover, the Black-Scholes model is not capable of correctly pricing in investors' preference for such an option contract when there is high political uncertainty.

The dynamics between the implied levels of skewness and kurtosis, and political uncertainty is found to be ambiguous. While there is a significant positive relation between skewness and kurtosis, and mean level of political uncertainty, more negative levels of skewness are related to increasing levels of political uncertainty. Also, it is found that when skewness is below its median value, political uncertainty is more volatile, and has more extreme high values. These results provide evidence that the levels of skewness and kurtosis, and thus the shape of the expected return distribution, are related to political uncertainty. Even though the exact dynamics between skewness, kurtosis, and political uncertainty, are yet to be uncovered, the conclusion that they are related to political uncertainty makes them a compelling candidate to examine the political risk premium pricing mechanism.

Finally, political uncertainty is regressed on the decrease in mispricing after controlling for skewness and kurtosis. Higher levels of uncertainty are related to a larger reduction is mispricing, indicating that non-normal expected return distributions are at least in part responsible for pricing the political risk premium. The results are in line-with, both Corrado and Su (1997) and Kelly et al. (2016). The skewness and kurtosis adjusted pricing model does not suffer from a pricing bias relative to moneyness, as seen with the Black-Scholes model. The extended pricing model is prone to some mispricing, however, smaller in size and less affected by political uncertainty than the Black-Scholes model.

Especially in-the-money call option contracts benefit the most from the skewness and kurtosis extension. The expected decrease in mispricing at the 10% lowest value of political uncertainty is £0.71 and increased to £4.37 at the highest 10% of uncertainty values. Although the total expected decrease in the mispricing of an at-the-money option is larger after controlling for skewness and kurtosis, the incremental effect of political uncertainty is smaller. For an at-the-money call option, the expected decrease in mispricing at the 10% lowest value of political uncertainty is £4.56 and increases to £5.78 at the highest 10% of uncertainty values. For out-of-the-money call options, no difference in pricing accuracy was found, except at high levels of political uncertainty.

In order to test the economic significance of these findings, a trading strategy is deployed using both the original and adapted pricing model to predict price changes. On a daily basis, FTSE 100 options contract trades are simulated. The focus lies on exploring at what level of uncertainty a higher return can be accomplished using the skewness and kurtosis adjustment in a scenario with and without transaction costs. Results show that the adjusted option pricing model performs exceptionally well compared to the original model when uncertainty is high. When political uncertainty is low, similar trading returns are achieved. These results are robust under transaction costs and even enlarge under some scenarios. Trading based on the Black-Scholes pricing model is more negatively affected when transaction costs are introduced, as compared to the extended model. It can be concluded that the pricing of political uncertainty through non-normal expected returns is significant both statistically and economically.

The main contribution of this paper is the evidence that the political risk premium is priced into options through non-normal expected return distributions. Another contribution lies in the extensive dataset used spanning 15 years of daily FTSE 100 equity index data. This allows for an analysis of many both low and highly politically uncertain periods, adding robust evidence to the body of literature on the political risk premium. Also, it is shown that superior options pricing estimates can be obtained by relaxing the assumption of lognormal returns in the Black-Scholes model. Finally, using the simulated trading results, it is shown that it can be economically significant to introduce non-normality into the Black-Scholes option pricing model.

Some limitations and future research recommendations are discussed. The analysis of the dynamics of the non-normality and political uncertainty can be extended. Although existing literature suggests that political uncertainty is accompanied by negative skewness and excess kurtosis, no such direct relation is found. Another recommendation is the inclusion of actual trading data, including bid-ask spreads, in the analysis. The analysis in this paper is limited by the use of daily closing prices, which do not reflect possible liquidity issues encountered at extreme levels of moneyness.

In the next part of this paper, the literature on the political uncertainty premium in asset and option prices will be discussed. In the Method section, the procedure used to answer the research question is elaborated. Including the data collection, option pricing models, regression, and time-series models are explained. In the Results section, summary statistics, and regression results, as well as the option trading performances are presented. Finally, the results are discussed, implications derived, and suggestions for future research are made.

Background

Asset Prices and Political Uncertainty

Before exploring how political uncertainty is priced into options, it should be questioned why asset prices are affected by political uncertainty. Pástor & Veronesi (2013) developed a general equilibrium model relating the equity risk premium caused by political uncertainty to economic conditions. In their model, government policy is seen as an uncertain variable, and asset prices react to news about the impact of current and future economic policy. There is a difference in the source of political uncertainty in good or bad economic conditions. In order to distinguish these sources, Pástor & Veronesi separate three types of shocks: capital shocks, impact shocks, and political shocks.

The first two shocks, capital shocks and impact shocks, are defined as fundamental economic shocks. Capital shocks are economic events that directly affect stock prices. Impact shocks also affect stock prices, however, indirectly. Impact shocks are events that lead investors to change their beliefs about the impact of current government policy on aggregate capital.

The third type, political shocks, is not directly related to aggregate capital. Political shocks influence the believes investors have regarding the cost of future government policies. These shocks are part of the ongoing process of policymaking in politics. Although political shocks have no direct effect on stock prices, the beliefs about the effects of future government policies are important for today's stock prices. Investors demand a premium to compensate for the uncertainty induced by political shocks, referred to as the political risk premium.

An important argument made to justify the political risk premium is the observation that political uncertainty affects all firms, and thus, all stock prices. Political uncertainty makes stock prices more correlated and is impossible to diversify away fully. Arguably, in an international portfolio, there exists some possibility to diversify the exposure to political uncertainty. However, there is a tendency of political uncertainty to spillover between countries (Kelly et al., 2016).

A conclusion made by Pástor & Veronesi (2013) is the influence of the economic state on two components of the risk premium: impact shocks and political shocks. During weak economic conditions, current economic policy is unlikely to be kept in place. As a result, the effect of political shocks is large. Meanwhile, impact shocks are less important, as the current policy is likely to be replaced.

In strong economic conditions, news about possible policy changes is less important since it will be changed less often. Impact shocks, news about current economic policy, have a larger impact in strong economic conditions because the current economic policy is likely to be maintained. Moreover, the impact of political shocks becomes larger when it is more precise.

Combining these results provide an ambiguous view on the effect of policy changes on asset prices. The tendency of government to change economic policies when the economy is in poor condition provides implicit put protection (Pástor & Veronesi, 2013). However, political uncertainty simultaneously reduces the value of the implicit protection, as the uncertainty about the impact of future policy changes increases the political risk premium as well.

Options Prices and Political Uncertainty

Having gained some understanding about the effect of political uncertainty on stock prices, the next question to ask is how political uncertainty is reflected in options prices. In general, options have value because uncertainty exists about future stock prices. It can be expected that options that protect against or provide the possibility to speculate on political uncertainty gain in value in an environment with high political uncertainty. However, the implicit put protection provided by government policy changes lowers uncertainty of stock prices, and thus the value of options.

There exists evidence on the dynamics of option prices under political uncertainty. Kelly, Pastor, & Veronesi (2016) isolate the effect of political uncertainty by comparing options that mature before and after elections or global summits. In summary, they predict that options with maturities spanning uncertain political events are more expensive, especially when economic conditions are weak.

Empirical support for their findings is made by analyzing option prices from twenty countries. A one-month put option that is 5% out-of-the-money is 9.6% more expansive when it has an expiration date just after an election, compared to just before. A 10% out-of-the-money put option is 16.0% more expansive when its lifetime spans political events. The intuition behind this approach is that the uncertainty induced by the political event is resolved after the election or summit has passed. As the uncertainty resolves, asset prices will adjust accordingly. The out-of-the-money put options gain the most value when there is political uncertainty, implying that investors prefer options that profit from downward price movements.

The model used by Kelly, Pastor, & Veronesi (2016) considers three factors that influence option prices: price risk, tail risk, and variance risk. Price risk relates to the risk of a change in the value of the underlying asset. Variance risk to the possibility that the volatility of the underlying asset changes. Tail risk is the risk that a price drop might be large. Tail risk is implicitly associated with negative skewness; however, it is not measured as such. The slope of the implied volatilities with respect the moneyness is used as a measure for tail risk. A higher slope, meaning that out-of-the-money put options are more expansive, indicating higher tail risk and thus negatively skewed returns.

The observed risk measures that are derived from option prices are all positively related to political uncertainty. Even though the observed prices do not comply with the Black-Scholes pricing model, it is still used to price options under political uncertainty. As common in literature, deviations are fit into the Black-Scholes model by adjusting the volatility so that the resulting prices align with observed ones.

Non-Normality and Option Prices

The Black-Scholes option pricing formula depends on five input variables: The current price of the underlying asset, the strike price, volatility of the underlying asset, interest rate, and time to maturity. All but the volatility is directly observable from either the asset markets or the contact itself. At first, sight, calculating the historic volatility could be a good candidate to use as input. However, there are reasons not to use historical volatility. Most importantly, historical volatility has a tendency to overprice options with high standard deviation estimates, and vice versa for low volatility estimates (Whaley, 1982).

The most common method for selecting a volatility estimate is deriving an estimate based on existing option prices. Instead of using the volatility to estimate the option price, the option contract prices are used to infer the volatility. There are multiple methods for estimating implied volatility. One such method estimates volatility by minimizing the sum of squares of the difference between observed option prices and the price estimate produced with the volatility estimate (Whaley, 1982). This method effectively finds the volatility that is the best fitting estimate of the observed prices. A necessity for this method is the availability of multiple option prices with similar maturities on the same underlying asset.

Whichever method is used to estimate the implied volatility, mispricing biases have consistently been documented using the Black-Scholes pricing model. Especially biases related to time to maturity and moneyness are the topic of a vast body of literature. Studies have found biases of both over- and underpricing out-of-the-money and in-the-money options

(Black, 1975), (Emanuel & MacBeth, 1982), (MacBeth & Merville, 1979), (Rubinstein, 1985).

In either case, the pricing bias is referred to as the implied volatility smile or smirk, corresponding to the shape of the curve of the plotted implied volatilities of option prices with different levels of moneyness and time to maturity. Studies have paid attention to explaining and predicting the implied volatility surface (Cont & da Fonseca, 2002), (Gonçalves & Guidolin, 2006), (Skiadopoulos et al., 2000).

Gonçalves & Guidolin (2006) used the predictability in time-varying implied volatilities of S&P500 options to de-bias option prices. It is possible to create highly accurate option price estimates using simultaneously both the Black-Scholes model and a prediction of how the Black-Scholes model produces biased implied volatilities.

While early studies concluded that stock price returns are non-normally distributed, the Black-Scholes model assumes they are lognormally distributed (Black & Scholes,1972). Moreover, the Black-Scholes model assumes that volatility is a characteristic of the underlying asset. As a result, the volatility must be independent of the strike price of an asset's option derivative. In this light, de-biasing option prices by changing implied volatility based moneyness becomes rather inconvenient, as it violates the volatility characteristic assumption. If the observed pricing biases are the result of non-normality translated into option prices, manipulating volatilities would merely be a cover-up of the actual problem, the unrealistic assumption of lognormal stock returns.

Instead of working around the boundaries of the Black-Scholes model, it is also possible to change the assumptions in a way that provides a better fit with reality. A seminal paper presenting such an approach is Jarrow and Rudd (1982). Using a series expansion that accounts for higher moments, any probability distribution can be approximated. Such distribution can reflect non-normal value of skewness and kurtosis. By using the approximated probability distribution, the Black-Scholes formula is extended with an additional term for every higher moment added. Each additional term represents the pricing adjustment made as a result of including the higher moment. In the case where skewness and kurtosis are added alongside volatility, the extended Black-Scholes pricing formula also needs two additional input variables for skewness and kurtosis.

Using higher moments, it is possible to de-bias option prices without manipulating volatilities. Corrado and Su (1997) use a pricing model mostly similar to the one developed by Jarrow and Rudd (1982). The main difference is that Jarrow and Rudd account for deviations in lognormality in stock prices, while Corrado and Su account for deviations from normality in stock returns. Their model uses a Gram-Charlier series expansion to approximate the probability distribution based on single estimates of volatility, skewness, and kurtosis. In theory, even higher moments could be added. However, these have little economic relevance and become highly correlated (Corrado and Su, 1997).

Corrado and Su (1997) test their pricing model out-of-sample on actual option trading data of options contracts on Telephonos de Mexico between 1993 and 1994. On average, the observed price deviation, as measured by the deviation from the bid-ask boundaries, was about half the size found with the Black-Scholes model. Were Black-Scholes had average mispricing of \$0,76 per contract, the Gram-Charlier based model was, on average, \$0.40 outside the bid-ask boundaries per contract.

Moreover, there was no systematic pricing bias related to the option moneyness after higher moments where included. Where the Black-Scholes model had a strong tendency to overprice in-the-money options and underprice out-of-the-money options, the Gram-Charlier model had no relation between mispricing and moneyness. These results suggest that non-normality could be one of the sources of option mispricing.

Similar to the original Black-Scholes model, there is the issue of having to select appropriate input values. In addition to volatility, skewness and kurtosis need to be estimated. However, it can be expected that using historical values will result in pricing biases for the same arguments as with the Black-Scholes model. Corrado and Su (1996) solve this issue by extending the simultaneous equation procedure suggested by Whaley (1982) to obtain volatility estimates in the Black-Scholes model. In addition to finding the best fitting estimate for volatility, simultaneously skewness and kurtosis levels are estimated by producing the best estimate given the available option price data.

The difference between the pricing estimate of the adjusted model compared to the Black-Scholes model depends on the estimated parameters of skewness and kurtosis. Because the basis of Black-Scholes is kept intact, the same price estimates would be obtained from the Gram-Charlier model if skewness was estimated at 0, and kurtosis at 3. Negative skewness would result in a negative price adjustment for out-of-the-money call options compared to in-the-money options. The intuition behind this mechanism lies in the reduced chance of the out-of-the-money option to become in-the-money when the change of a greater than average spot price decreases, while the change of a below-average spot price increases. Whenever there is positive skewness, the mechanism works in the opposite direction. Under positive skewness, out-of-the-money call options increase in value compared to in-the-money options (Heston, 1992).

The price adjustment for non-normal levels of kurtosis is symmetric. Above normal levels of kurtosis increase the probability of spot price return values that are both far above or far below average. This decreases the value of at-the-money options and increases the value of both options further in- and out-of-the-money.

Adding higher moments to the Black-Scholes model seems to be beneficial. The assumption of lognormality in returns is not violated, and unbiased pricing estimates can be obtained. However, the original Black-Scholes is still one of the most important option pricing models in academia. The reason could be that economists are simply accustomed to normal distributions since most financial models are builds on the assumption of normality.

Non-Normality and Political Uncertainty

Kelly et al., (2016) showed that investors are willing to pay for insurance against or the possibility to benefit from the increased tail risk associated with political uncertainty. These results suggest that political uncertainty does not merely increase the volatility of expected return distribution, but also changes the shape of the return distribution due to non-normal levels of skewness and kurtosis. The Gram-Charlier option pricing model predicts that out-of-the-money put's and in-the-money calls are more expansive under negative skewness. Relating these findings to Kelly et al., (2016) suggests that political uncertainty is associated with negative skewness.

A limitation of the findings by Kelly et al., (2016) is the sole inclusion of election periods in the sample period. There is no existing evidence of how skewness behaves when the source of political uncertainty is unrelated to elections. When the source of political uncertainty is a rumor about a favorable interest rate change by the Bank of England, skewness levels might be positive. Intuitively, there is a relation between skewness and political uncertainty. However, the direction of the relationship might change depending on the source of political uncertainty.

Intuitively, kurtosis levels increase with political uncertainty. For instance, in parliamentary elections, any outcome that differs from the current situation is likely to result in a significant change in government policy. Markets expect a higher chance of observing a return far above or below average, resulting in leptokurtic expected returns.

Although suggested by the literature, there is no evidence on the pricing mechanism that prices political uncertainty through of skewness and kurtosis. In the next sections, the method used to test the existence of the pricing mechanism is explained and applied to FTSE 100 index options.

Method

Hypotheses

In answering the research question -"Is non-normality in expected return distributions responsible for the pricing of a political risk premium in options?" – it is useful to divide the problem into three separate hypotheses. First, before the pricing mechanism of political uncertainty can be examined, it must be determined if there is a political risk premium in options. Although existing literature suggests there is, looking into this question is interesting for two reasons. An extensive long-term dataset can provide additional robust evidence on the size and consistent presence of the political risk premium. Evidence of the existence of the political risk premium mainly focused on variation around political events and might be prone to cherry-picking. Also, if there is no evidence of the political risk premium in the dataset, examining the pricing mechanism would be meaningless.

The first hypothesis is directly derived from Kelly et al., (2016):

H_1: Higher political uncertainty is positively related to options misprizing, measured relative to the theoretical Black-Scholes option price.

The second step in analyzing the pricing mechanism of political uncertainty is testing if the levels of skewness and kurtosis are related to political uncertainty. If there is a political risk premium and it is price via non-normality, political uncertainty must be associated with the levels of skewness and kurtosis.

Kelly et al., (2016) suggest a negative relation between political uncertainty and skewness during elections periods. However, for the political uncertainty to be priced via non-normality, it not necessary to have a relation with stable coefficients. Political uncertainty can also be positively associated with skewness, as long as there is some relation to non-normality. The second hypothesis is derived from the Heston (1992), Corrado & Su (1997) and Kelly et al., (2016):

H_2: Implied levels of skewness and kurtosis are related to political uncertainty.

The third hypothesis is derived from the first two hypotheses. First, it will be established if there is a political risk premium by testing if theoretical option mispricing is increasing in political uncertainty. Second, it is determined if non-normality in implied return distributions is related to political uncertainty. However, one more step is needed to establish if the political risk premium is also priced in the options market.

If non-normality is (in part) responsible for option mispricing caused by political uncertainty, then the skewness and kurtosis adjusted pricing model should have less high mispricing under high political uncertainty, compared to the Black-Scholes model. Stated as the following hypothesis:

H_3: The difference in theoretical option mispricing between the Black-Scholes and the for skewness and kurtosis extended model is increasing in political uncertainty.

The final hypothesis is related to the economic significance of including non-normality in option pricing. The theoretical returns achieved by both pricing models can be compared under different levels of political uncertainty. The theoretical framework suggests that under high political uncertainty, the extended option pricing model should outperform the Black-Scholes model, indicating an economically significant difference. The following hypothesis will test if, and at which level of political uncertainty, it is economically meaningful to implement skewness and kurtosis in option pricing:

H_4: The difference between option-trading returns achieved with Black-Scholes, and the skewness and kurtosis adjusted option pricing models is increasing in political uncertainty.

Data Collection

FTSE 100 index option price data was retrieved from Datastream. The data includes daily prices in Pound Sterling of options with nine constant levels of moneyness ranging from 80% in-the-money, up to 120% out-of-the-money. Moneyness is defined as the strike price divided by the spot price. All prices are based on a constant time to maturity of 30 days. Because not all days have an actual expiry, the 30-day time to maturity continuous series of prices is created by Datastream by applying a weighting mechanism between the nearest available 30-day contracts. Thus, the prices are not solely actual trading prices, but also supplemented by estimates provided by Datastream. Although longer-term maturities are available, up to 5 years, only short-term contracts are used in order to capture the most variation of political uncertainty at that particular point in time.

Additionally, the corresponding input variables of the option pricing models are retrieved from Datastream for every date. The interest rate used is the 12-month Libor rate.

Ideally, the interest rate corresponding to the maturity of the contract is used, however only the 12-month rate is available, and the sensitivity of the option prices with respect to the interest rate ("Rho") is low in general. The London interbank rate is used as a risk-free rate since this rate is the most representative of the actual interest rate charged to option-traders, as compared to government bond risk-free rates.

Political Uncertainty Measure

As a measure for political uncertainty, the UK Daily Economic Policy Uncertainty (EPU) Index is used, retrieved from *www.policyuncertainty.com*. The index is constructed base on the method developed by Baker, Bloom, and Davis (2016). Uncertainty is measured in the index by counting the number of newspaper articles that mention the terms "economic" or "economy" and "uncertain" or "uncertainty" and "spending," "deficit," "regulation," "budget," "tax," "policy," or "Bank of England." The data covers all dates for which option price data was retrieved. In total, articles are used from 650, both local and national newspapers.

The final index number is created by aggregating the daily number of articles that mention one of the relevant terms. The number is normalized to account for the increasing quantity of newspapers included in the index over time.

Option Price Estimates

Before comparing the different pricing models in the light of political uncertainty, pricing estimates from both models are needed. For the Black-Scholes model, all but one variable is readily available. However, since the FTSE 100 index consists of dividend-paying stocks, and the Black-Scholes model assumes stocks are non-dividend paying, some adjustments need to be made. Because a stock loses value whenever it goes ex-dividend, call options lose value whenever such an event takes place. In accordance with Black (1975), the present value of the announced dividends over the option's maturity is subtracted from the spot price of the index. The dividend-adjusted spot price is used in the option price calculation.

For each day, a single volatility is estimated using the simultaneous equation procedure from Whaley (1982). This procedure relies on minimizing the sum of squares of the difference between the observed option price, and the Black-Scholes option price, using N options with the same time to maturity:

$$\min_{BSISD} \sum_{j=1}^{N} \left[C_{OBS} - C_{BS.j}(BSISD)\right]^2$$

Where C_{OBS} is the observed call price, C_{BS} the Black-Scholes call price, and *BSISD* the implied standard deviation. Using the original Black-Scholes option pricing model:

$$C_{BS} = S_0 N(d) - Ke^{-rt} N\left(d - \sigma\sqrt{t}\right)$$

and:

$$d = \frac{\ln\left({S_0}/{K}\right) + \left(r + {\sigma^2}/{2}\right) t}{\sigma\sqrt{t}}$$

The extended skewness and kurtosis adjusted model combines the Black-Scholes model with an extension for the higher moments. The Gram-Charlier model developed by Corrado & Su (1997) is used:

$$C_{GC} = C_{BS} + \mu_3 Q_3 + (\mu_4 - 3) Q_4$$

Where C_{GC} is the adjusted call price, μ_3 and μ_4 are the parameters for skewness and kurtosis, respectively. The expressions for the skewness and kurtosis price adjustments are:

$$Q_3 = \frac{1}{3!} S_0 \sigma\sqrt{t}\left(\left(2\sigma\sqrt{t} - d\right) n(d) + \sigma^2 t N(d)\right)$$
$$Q_4 = \frac{1}{4!} S_0 \sigma\sqrt{t}\left(\left(d^2 - 1 - 3\sigma\sqrt{t}\left(d - \sigma\sqrt{t}\right)\right) n(d) + \sigma^3 t^{3/2} N(d)\right)$$

Similar to the procedure used with the Black-Scholes model, the simultaneous equation procedure can be used to estimate the three missing variables for the extended model: Gram-Charlier implied volatility (ISD), implied skewness (ISK) and implied kurtosis (IKT). Using N option contracts with the same time to maturity, the procedure looks as follows:

$$\min_{ISD,ISK,IKT} \sum_{j=1}^{N} \left[C_{OBS} - \left(C_{BS.j}(ISD) + ISK\, Q_3 + (IKT - 3) Q_4\right)\right]^2$$

The out-of-sample option prices for both models are calculated using the most recent values for volatility, skewness, and kurtosis. Thus, the values derived from today's options data are used to estimate the value of options on the next trading day. In summary, this method provides us with a pricing estimate from the Black-Scholes model and an estimate from the skewness and kurtosis adjusted model, which we can compare to the observed prices. Alongside these price estimates, we have daily levels of Black-Scholes implied volatility and Gram-Charlier volatility, skewness, and kurtosis.

Trading Simulation Price Data

The options pricing data available only includes prices with a constant time to maturity of 30 days. As a result, it is not possible to directly observe the price change of options from one day to the other. In order to get an estimate of the actual observed price changes from one day to the other, a manipulation of the option prices is made.

For each observed option price, the Black-Scholes implied volatility is back-solved. Using this implied volatility, the time-adjusted price is calculated using the Black-Scholes model; however, with the lower time to maturity, mimicking today's price of an option available one trading day prior.

The key assumption made in this procedure is that the expected return distribution of options with a maturity differing by one trading day remains approximately equal. This way, only the change in time to maturity significantly affects the value of the option. As with the original dataset, where some prices are not direct market quotes, these prices are also not directly observed from financial markets. However, for the purpose of this paper, they provide an adequate estimate.

Regression Models

In this section, the statistical procedures used in testing the hypotheses are presented.

Hypothesis 1

A regression model will be made to test the first hypothesis. The dependent variable is defined as the observed call price minus the theoretical estimated Black-Scholes call price:

$$Black - Scholes\ mispricing = \ C_{obs} - C_{bs}$$

The main independent variable is the daily Economic Policy Uncertainty Index.

Deep out-of-the-money options are naturally much less expensive than deep-in-the-money options. The resulting option mispricing in absolute terms might be much higher for deep-in-the-money options, making it impossible to directly compare the mispricing of options with different levels of moneyness. A straightforward solution to this problem would be to use mispricing specified relative to observed option prices. However, this would result in another problem. In a relative mispricing specification, low-value out-of-the-money options are prone to substantial values of relative mispricing, even when mispricing is small in absolute terms.

To solve this issue, we need to control for the effect of political uncertainty relative to moneyness directly in the model. With this method, the effect of uncertainty can be distinguished for each level of moneyness. Kelly et al., (2016) find the political risk premium in put contracts progressively increases when it comes out-of-the-money, suggesting a nonlinear relation between moneyness and political uncertainty in mispricing.

Additionally, moneyness should be included as a standalone control variable to control for the volatility smile or smirk. Gonçalves & Guidolin (2006) show that a nonlinear model of moneyness and time to maturity has excellent predictive power of S&P500 options. Since only one type of time to maturity is used, there is no need to include it as a control variable. Thus, the regression model should control for the nonlinear relation between moneyness and mispricing, and the uncertainty relative to moneyness:

$$C_{obs} - C_{bs} = \beta_0 + \beta_1 EPU_i + \beta_2 EPU_i * M_i + \beta_3 EPU_i * {M_i}^2 + \beta_4 M_i + \beta_5 {M_i}^2{}_i + \mathcal{E}_i$$

$$Mispricing\ (£) = \beta_0 + \beta_1 EPU_i + \beta_2 EPU_i * M_i + \beta_3 EPU_i * {M_i}^2 + \beta_4 M_i + \beta_5 {M_i}^2{}_i + \mathcal{E}_i$$

After obtaining the regression results, the statistical significance of the coefficients is tested using a two-sided F-test. Most important is the simultaneous significance of Beta 1, 2 and 3, as they relate to political uncertainty. If uncertainty is not related to mispricing, all these coefficients cannot be significant.

Hypothesis 2

In order to test the second hypothesis, a time-series regression model will be made. The dependent variable used is the Economic Policy Uncertainty Index, the independent variables the daily skewness and kurtosis levels derived in the simultaneous equation procedure. In contrast to the analysis on option mispricing, there is one daily observation instead of an observation for each option price. A lagged political uncertainty variable will be included to solve the issue of serial correlation in uncertainty levels.

Because the errors of the ordinary time-series regression on political uncertainty are highly heteroskedastic, a GARCH(1,1) (generalized autoregressive conditional heteroscedasticity) is used to separately model the variance of the time series model (Bollerslev, 1986). The first- and second-order difference of the uncertainty index is also included to get a more elaborate understanding of the dynamics between non-normality and political uncertainty. The general model looks as follows:

$$EPU_i = \beta_0 + \beta_1 Skew_i + \beta_2 Kurt_i + \mathcal{E}_i$$

With a GARCH(1,1) variance equation:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2$$

Similar as with Hypothesis 1, the statistical significance of the coefficients of skewness and kurtosis are tested using an F-test.

Hypothesis 3

The first hypothesis tested if there was a political risk premium. The second hypothesis tested if non-normality in expected return distributions is related to political uncertainty. These tests should indicate if the political risk premium is priced via non-normality. The last step directly examines the pricing of political uncertainty by comparing the price estimates of the Black-Scholes and extended pricing model with respect to political uncertainty.

Different methods are considered for testing the final hypothesis. A similar approach to the first regression model used to test the existence of the political risk premium was considered. Instead of using Black-Scholes mispricing, it uses the mispricing of the extended model. If there is a significantly smaller relation between the mispricing of the extended model and political uncertainty, compared to the Black-Scholes regression coefficient, part of the premium is priced in through non-normality.

However, comparing the two regression models would likely result in a statistical complication. Since it is likely that the dependent variables, mispricing of both models, are correlated to some extent, directly comparing both coefficients is not possible. In order to bypass the statistical complication, one dependent variable is created that incorporates all relevant information. The main advantage of this approach is the possibility to compare the mispricing of individual options between both models.

The dependent variable of the final model will be the difference in absolute mispricing between the Black-Scholes model, and the absolute mispricing of the skewness and kurtosis adjusted model. The independent variables will be the same as in the first model, including the Economic Policy Uncertainty index, moneyness, and their nonlinear interactions:

$$|C_{obs} - C_{bs}| - |C_{obs} - C_{GC}| = \beta_0 + \beta_1 EPU_i + \beta_2 EPU_i * M_i + \beta_3 EPU_i * {M_i}^2 + \beta_4 M_i + \beta_5 {M_i^2}_i + \mathcal{E}_i$$

$$Mispricing\ difference\ (£) = \beta_0 + \beta_1 EPU_i + \beta_2 EPU_i * M_i + \beta_3 EPU_i * {M_i}^2 + \beta_4 M_i + \beta_5 {M_i^2}_i + \mathcal{E}_i$$

The significance of political uncertainty on the mispricing difference is tested using an F-test on Beta 1, 2, and 3.

Hypothesis 4

A simple linear regression will test the significance of the different simulated trading returns of the skewness and kurtosis adjusted Gram-Charlier (GC) model, and the Black-Scholes (BS):

$$Return\ difference\ GC - BS_i = \beta_0 + \beta_1 EPU_i + \mathcal{E}_i$$

In essence, the model is similar to the one used to test Hypothesis 1 and 3. The main difference is that there is no need to control for moneyness. Because daily returns are compared, instead of individual options, moneyness is not part of the equation.

The main advantage of applying a trading strategy is the ability to correct for transaction costs. Being able to produce a superior pricing estimate of political uncertainty only has statistical significance if the improved price estimate is sufficient to cover transaction costs incurred when trying to exploit the information advantage.

Because the dataset used does not contain actual bid-ask spreads, the effect of transaction costs is mimicked by applying a fixed cost for each option contract bought and sold; the round-trip cost. Based on the approach used by Goncalves & Guidolin (2006), two levels of transaction costs are considered: 5 cents and 12,5 cents per round-trip. Also, a base case without any transaction costs is presented.

Arguably, using fixed transaction costs makes it unfavorable to trade in deep-out-of-the money option contracts since these are naturally less costly than in-the-money contracts. Because a trade in a cheap option contact would have a higher volume, more transaction costs are incurred compared to a trade of the same size in a more expensive contract. However, deep-out-of-the-money options are known to have the highest bid-ask spread, making the fixed cost an assumption most closely resembling reality in the absence of actual costs (Ferreira et al., 2003).

Trading Simulation Rules

Two different trading strategies are simulated for each pricing model, named "Division" and "Max." Both strategies start each trading day with a fictional £1000 of funds available and assume options are only held for one day. This way, daily returns can be easily compared. All trades are delta hedged by borrowing funds against the 12-month LIBOR rate. This way, the effect of the spot price of the FTSE 100 index on the option's value is excluded. The transaction costs apply both to the option contracts and delta hedging trades.

The distinction between the two trading strategies lies in selecting the traded options contracts. The Division strategy divides all available funds equally over the options with positive expected profits, whereas the Max strategy only selects the contract with the highest expected payoff. The distinction between the two strategies is based on the options trading strategies used by Gonçalves & Guidolin (2006), who used different strategies to provide insights into the robustness of the obtained results. By simulating trades in both a variety of options, and a single daily option, it is possible to explore at which level of moneyness the most profitable opportunities are identified, and how they change under transaction costs.

The decision to trade in an option contract is based on the expected profit from making a particular trade. If the pricing model predicts the option price to increase tomorrow, expected trading profits are calculated by multiplying the price increase by the number of contracts possibly bought with the available funds. The transaction cost and borrowing costs are subtracted from the expected trading profit, for contract i:

$$\begin{aligned} &Expected\ trading\ profit_i \\ &= (price\ change_i - transaction\ costs) * \left(\frac{contract\ price_i}{available\ funds}\right) - delta\ hedge\ cost \end{aligned}$$

Because options are only held for one day, the final payoff of each trading day is calculated by taking the actual price change of each traded contract, multiplied by the number of contracts traded. The incurred transaction costs and delta hedging payout are added to obtain the daily profit or loss. The profit for each trading day with N different traded contracts is as follows:

$$Daily\ profit = \sum_{i=1}^{N} (price\ change_i - \ transaction\ cost) * \ number\ of\ contracts\ bought_i \\ - \ delta\ hedge\ borrowing\ cost_i + payoff\ delta\ hedge_i$$

Summary Statistics

In this section, the obtained summary statistics are presented. Table 1 includes the summary statistics of the data. The observed option prices have a mean value of £373.91. Deep out-of-the-money options are mostly valued close to zero, whereas in-the-money contracts are priced more expansive. Both the Black-Scholes and Gram-Charlier options pricing model have, on average, a tendency to underprice options by £2.45 and £0.63, respectively. Looking at all pricing estimates together, it can be concluded that the skewness and kurtosis extended pricing model yields a more accurate price estimate.

The implied levels of skewness and kurtosis derived using the simultaneous equation procedure were -1.10 and 3.96 on average. These levels imply negative skewness and excess kurtosis, and thus non-normality in expected returns. The standard deviations of skewness and kurtosis are 0.29 and 0.56, respectively, indicating that the state of negative skewness and excess kurtosis is most often observed. In total, 98% of daily return distribution observations showed negative skewness and excess kurtosis. The implied volatility levels in the Black-Scholes model is 17.03%, whereas the implied volatility of the Gram-Charlier model is somewhat higher at 20.07%.

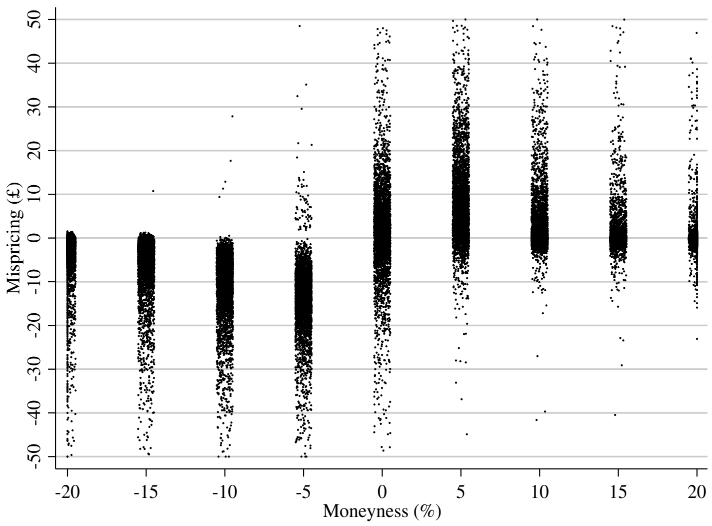
The Economic Policy Uncertainty Index, used as the proxy for political uncertainty, has a mean value of 317.93. The maximum value of 2610.06 was achieved after the first Brexit referendum on June 23th 2016. The lowest value of 0 was observed ten separate days.

The mean absolute value of the reduction in option mispricing after using the extended pricing formula, compared to the Black-Scholes model, was £1.31. The absolute values are used to compare individual option mispricing of both models independent of the direction, under- or overpricing.

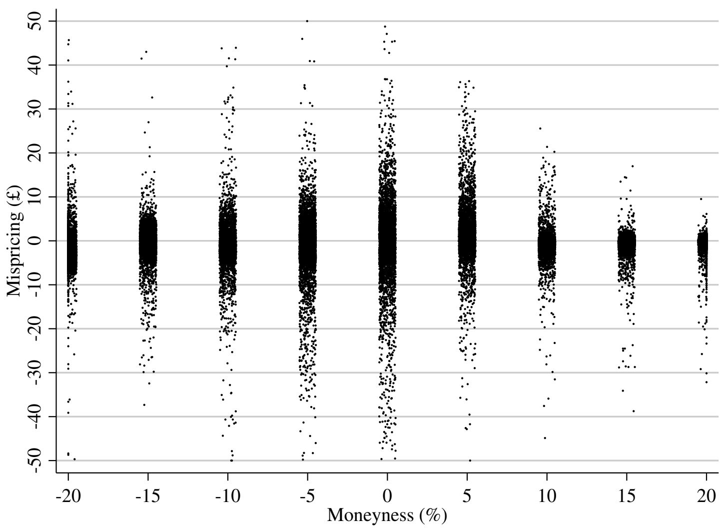
Tabel 1: Summary statistics FTSE100 Option prices and Poltical uncertainty

Variable	Mean	Std. Dev.	Min	Max
Observed Call price (£)	373.91	441.98	0.00	1,560.14
Black-Scholes call price (£)	371.46	438.44	0.00	1,559.63
Gram-Charlier call price (£)	373.28	441.48	0.00	1,557.76
Moneyness (K/S)	1.00		0.80	1.20
Whaley Black-Scholes Implied volatility (%)	17.03	8.22	6.26	67.77
Whaley Gram-Charlier Implied volatility (%)	20.07	9.39	4.21	78.88
Skewness	-1.10	0.29	-2.15	0.24
Kurtosis	3.96	0.56	1.21	6.92
FTSE 100 Index price (£)	6,214.12	853.41	3,512.09	7,877.45
Political Uncertainty Index	317.93	196.45	0.00	2,610.06
Black-Scholes mispricing (£)	-2.45	10.32	-49.75	49.81
Gram-Charlier mispricing (£)	-0.63	6.63	-75.59	80.86
Decrease in absolute mispricing (£)	3.39	6.70	-63.12	48.23
Observations	31,649			
Time span (Days)	3,518		24/11/2005	08/05/2020

Graph 1 and 2 present the theoretical option mispricing of both models with respect to the option moneyness. The Black-Scholes model has a bias of underpricing in-the-money options and overpricing out-of-the-money options. The Gram-Charlier model, although not exempt from mispricing, does not exhibit a structural pricing bias related to moneyness.



Graph 1: Black-Scholes Option mispricing and Moneyness

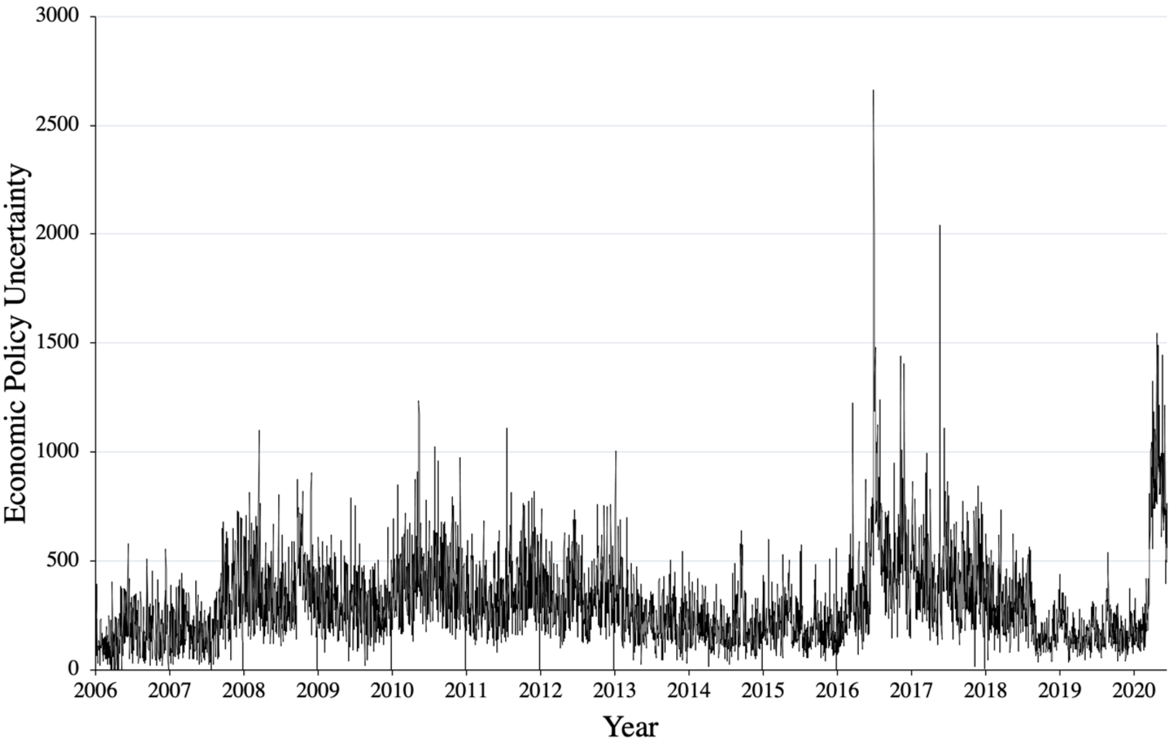


Graph 2: Gram-Charlier Option Mispricing and Moneyness

Uncertainty Timeline

Graph 3 presents the timeline of the Economic Policy Uncertainty index. Periods of high uncertainty are seen during the economic crisis of 2008 and the European monetary crisis during 2010. Also, especially after the unexpected result of the Brexit referendum, the highest values are recorded. Alongside the arrival of the COVID-19 virus and the economic impact of the economic lockdowns, the beginning of 2020 marks an increase in political uncertainty

Periods of high uncertainty go hand in hand with periods of high volatility. Low index values can be observed during periods of high uncertainty. It must be emphasized that the index is based on newspaper articles. Possibly newspapers are sometimes not interested in publishing articles containing topics related to economic policy uncertainty. However, uncertainty may persist in the expectations of investors. For instance, even throughout the years of the economic crisis, there was an index value of zero during Christmas time.



Graph 3: Economic Policy Uncertainty Timeline (Baker, Bloom & Davis, 2016)

Main Empirical Results

Political Risk Premium

The existence of a political risk premium was tested using a regression of political uncertainty on theoretical Black-Scholes option mispricing. Table 2 presents the results. Model 1 is the most basic setup, only including political uncertainty as an independent variable. There is a significant negative relation between political uncertainty and Black-Scholes option mispricing. Observed call prices are higher compared to theoretical Black-Scholes prices when uncertainty is higher. When the index level of political uncertainty is 100 points higher, the expected observed call price exceeds the Black-Scholes prices by an incremental 7 pence. Note that the average value of political uncertainty corresponds roughly with the average Black-Scholes mispricing of -£2.45.

Model 2 includes control variables for moneyness. The effect of political uncertainty remains significant and negative, and the coefficient is even slightly larger. The linear variable of moneyness is significant and positive; the squared coefficient of moneyness is not significant. Meanwhile, the regression constant changed considerably compared to Model 1. Only in-the-money options are underpriced, options near at-the-money and out-of-the-money are expected to be overpriced under the Black-Scholes model. Compared to Model 1, R-squared increased from 0% to 15%, indicating that there is some explanatory power after controlling for moneyness.

The last model, Model 3, includes interaction variables between moneyness and uncertainty. All variables are significant at either a five or one percent level. Again, political uncertainty is associated with higher theoretical option mispricing. However, the direction of the effect now depends on the moneyness level of the call option. A 20% in-the-money call option becomes £1.30 more underpriced using the Black-Scholes model for every 100-point increase in the uncertainty index. Comparing the mispricing of a 20% in-the-money call when political uncertainty is at the 10% highest value (554), compared to the 10% lowest value (117), the options are underpriced by £15.19, compared to £9.75.

The 20% out-of-the-money call option is £0,63 more overpriced compared to its observed price for every 100-point increase in the uncertainty index. When political uncertainty is at the 10% lowest value, the 20% out-of-the-money is underpriced by 81 pence. At the 10% highest uncertainty value, it is overpriced by £1.93. At-the-money options are also more overpriced as uncertainty increases; however, only by £0.06 for every 100-point increase in the uncertainty index.

The obtained result confirms Hypothesis 1. Political uncertainty is positively related to theoretical Black-Scholes option mispricing in FTSE 100 index options. Under low political uncertainty, the Black-Scholes model has a bias of underpricing in-the-money options and overpricing out-of-the-money options. When political uncertainty is high, the mispricing is enlarged. There seems to be a pricing component associated with political uncertainty that is inadequately captured by the Black-Scholes model.

Table 2: Regression result for Political Uncertainty on Black-Scholes option mispricing

	Model		
Variable	(1)	(2)	(3)
Uncertainty (*100)	-0.07**	-0.10***	-13.86***
	(0.03)	(0.03)	(1.84)
Moneyness		43.22***	-28.54**
		(7.40)	(14.01)
Moneyness-squared		-5.63	22.71***
		(3.70)	(7.01)
Moneyness*Uncertainty (*100)			23.15***
			(3.73)
Moneyness-squared*Uncertainty (*100)			-9.23***
			(1.86)
Constant	-2.21***	-39.49***	3.41
	(0.11)	(3.65)	(6.91)
Observations	31,644	31,644	31,644
R-squared	0.00	0.15	0.17

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Political Uncertainty and Non-normality

The second hypothesis stated that skewness and kurtosis levels are related to political uncertainty. Table 3 presents the results from the GARCH(1,1) time series model.
The first equation analyses the mean level of political uncertainty. Both the coefficient of the lagged uncertainty and the expected return parameters are significant at a 1% level. An increase in the skewness of the expected return distribution is related to a 26.71 point higher political uncertainty level. Given that most levels of skewness are negative, the coefficient of skewness can be most easily interpreted as the more negative skewness becomes the lower expected political uncertainty. However, the size of the coefficient has little economic meaning. As most values of skewness are located around -1.10, little variation in political uncertainty can be ascribed to skewness—the same holds for kurtosis. Higher kurtosis is related to higher political uncertainty, even though the economic impact is limited. The level

of political uncertainty is, for a large part, related to its own lagged value. The coefficient of 0.63 indicates that high uncertainty is likely to be followed by high uncertainty.

The variance equation of the Mean model has highly significant ARCH and GARH coefficients. The sum of the coefficients is close to one, indicating that any shocks in the variance of the model are highly persistent over time. Periods of high volatility are followed by periods of high volatility, and vice versa. Similar significant results are found for the variance of both the first and second differences of political uncertainty.

In the First Difference and Second Difference model, the coefficients of skewness are significant at a 5% level. Negative levels of skewness are related to increasing political uncertainty. The size of the coefficients has more economic meaning compared to the Mean model. Although the marginal effect of -15.98 on the change of political uncertainty appears small in relation to the variations seen in skewness levels, prolonged periods of negative skewness could result in a meaningful impact on political uncertainty. The significant lagged first difference coefficient of -0.36 indicates that the large positive changes in political uncertainty are followed by smaller and negative changes and vice versa, all else equal.

In the Second Difference equation, the significant negative coefficient of skewness indicates that under negative levels of skewness, increasing rates of change in political uncertainty are expected. The lagged Second Difference coefficient of -0.59 is similar to the First Difference, indicating that large positive changes in the rate of change are followed by smaller or negative changes and vice versa, all else equal.

The constants of the first and second difference equations are not significant, indicating that there is no increasing or decreasing trend in the time series of political uncertainty. There is also no significant relationship between kurtosis and the first and second difference in political uncertainty. Whereas the level of skewness has some explanatory power on the change in political uncertainty, kurtosis does not. Possibly, the symmetrical impact of kurtosis in expected return distributions prevent it from affecting the direction of change in political uncertainty. Whereas negatively skewed expectations increase uncertainty, kurtosis is associated with both negative and positive extremes, and thus directionless.

Tabel 3: GARCH(1,1) time series model results for Skewness and Kurtosis on Political Uncertainty

Equation: Uncertainty			
Variable	**Mean**	**First difference**	**Second Difference**
Lag Uncertainty (t-1)	0.63***		
	(0.01)		
Lag FD Uncertainty (t-1)		-0.36***	
		(0.02)	
Lag SD Uncertainty (t-1)			-0.59***
			(0.01)
Skewness	26.81***	-15.98**	-20.15**
	(8.38)	(7.11)	(8.51)
Kurtosis	9.64***	-3.88	-5.54
	(3.69)	(3.47)	(4.72)
Constant	84.23***	1.09	-0.05
	(13.04)	(12.21)	(16.74)
Variance Equation			
ARCH(1)	0.12***	0.18***	0.27***
	(0.01)	(0.01)	(0.01)
GARCH(1)	0.88***	0.82***	0.73***
	(0.01)	(0.01)	(0.01)
Constant	171.36**	464.00***	1,700.72***
	(77.87)	(119.10)	(314.67)
Observations	3,462	3,352	3,249
AIC	43,554	42,186	43,137

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 4 presents the characteristics of the distribution of political uncertainty values when skewness and kurtosis are above and below their median values. The mean value of political uncertainty is somewhat lower when below-median values of skewness are recorded. The standard deviation is somewhat higher, 200.71, when skewness is below the median, compared to 181.26 above the median. Substantial differences are found comparing the skewness and kurtosis of the values of political uncertainty itself. The distribution of political uncertainty values is more positively skewed and has higher kurtosis when the options market has below-median negatively skewed return expectations. Thus, on average, skewness is positively associated with political uncertainty, but, below-median negative skewness is also associated with both more extreme high values of political uncertainty and a more extensive range of values far below and above the average level.

The differences are less pronounced when political uncertainty is compared between high and low levels of kurtosis. Besides a small increase in mean uncertainty, the high levels of kurtosis are associated with lower standard deviation, skewness, and kurtosis of political uncertainty levels. When the options market has an above-median leptokurtic return expectation, political uncertainty levels tend to have less extreme high values and more concentrated around the mean.

The results partially confirm Hypothesis 2. There is a relation between skewness, kurtosis, and uncertainty. However, the time-series coefficients for kurtosis are only significant in the Mean model. Overall, it appears that skewness is an important predictor of the distribution of values of the political uncertainty index. Skewness is also related to changes in political uncertainty. When investors have a negatively skewed expected return, uncertainty tends to move up at an increasing rate.

Tabel 4: Political Uncertainty Index statistics compared above and below median skewness and kurtosis levels

	Skewness:	
Uncertainty	Below median	Above median
Mean	302.46	323.19
Std. Dev.	200.71	181.26
Skewness	3.20	1.08
Kurtosis	26.25	5.35
	Kurtosis:	
Uncertainty	Below median	Above median
Mean	311.56	314.11
Std. Dev.	206.41	175.35
Skewness	2.48	1.92
Kurtosis	19.80	12.41

Note: The median values of skewness and kurtosis are -1.13 and 3.91 respectively.

Black-Scholes Compared to Gram-Charlier

Hypothesis 3 tested the mispricing of each pricing model vis a vis political uncertainty. Table 5 presents the results of the regression of the absolute decrease in option mispricing after implementing skewness and kurtosis into the pricing model. The first regression (1) solely includes political uncertainty as an independent variable. The coefficient is statistically significant at a one-percent level. A 100-point higher uncertainty level is associated with £0.40 lower options mispricing of the Gram-Charlier model, compared to the Black-Scholes model. When the level of political uncertainty moves from the 10% lowest value to the highest 10%, the reduction in option mispricing after implementing skewness and kurtosis is £1.74 higher.

After controlling for moneyness (2), the effect of political uncertainty remains robust. Overall, the decrease in option mispricing is most pronounced for near-at-the-money options.

Under low political uncertainty, there is no improvement in option pricing accuracy for deep out-of-the-money options after correcting for skewness and kurtosis.

Model 3 includes the interaction between uncertainty and moneyness. The significant positive effect of political uncertainty on the decrease in option mispricing is most reflected in deep-in-the-money call options. Deep in-the-money options are similarly mispriced by both Black-Scholes and Gram-Charlier when there is low political uncertainty. However, each 100-point increase in the uncertainty index is associated with £0.84 lower mispricing by the Gram-Charlier model, compared to Black-Scholes. At- and out-of-the-money options also exhibit lower mispricing under higher political uncertainty. However, the effect is smaller compared to deep-in-the-money options. The incremental effect of a 100-point increase in uncertainty on comparative mispricing for an at-the-money option is £0.28, and £0.39 for a 20% out-of-the-money option. The R-squared of Model 3 is 10%, indicating that the model explains some of the total variations observed.

Table 5: Regression result for Political Uncertainty on Absolute Decrease in Theoretical Option Mispricing

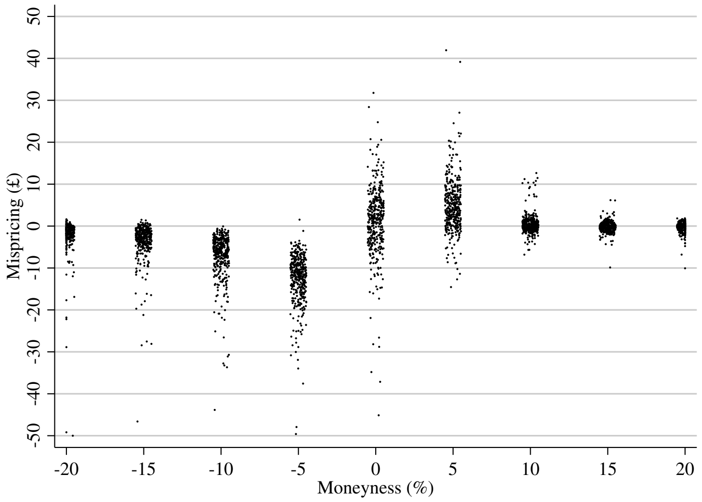
	Decrease in mispricing (£)		
Variable	(1)	(2)	(3)
Uncertainty (*100)	0.40***	0.42***	9.79***
	(0.02)	(0.02)	(1.25)
Moneyness		212.85***	269.55***
		(4.98)	(9.49)
Moneyness-squared		-110.67***	-137.23***
		(2.49)	(4.75)
Moneyness*Uncertainty (*100)			-17.89***
			(2.53)
Moneyness-squared*Uncertainty (*100)			8.38***
			(1.26)
Constant	2.11***	-98.39***	-128.09***
	(0.07)	(2.46)	(4.68)
Observations	31,644	31,644	31,644
R-squared	0.01	0.09	0.10

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

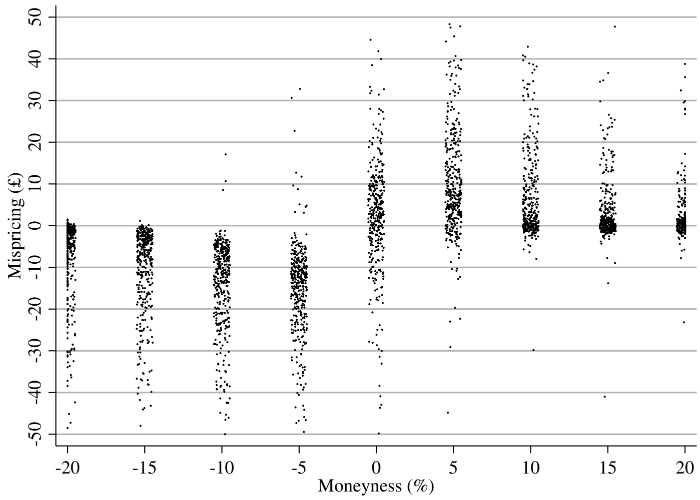
The statistical analysis is supported by Graph 4 and 5, showing the difference in Black-Scholes mispricing during the 10% lowest uncertain days (4), compared to the 10% most uncertain days (5). In both situations, there is a pricing bias of underpricing in-the-money options and overpricing out-of-the-money options. When uncertainty is high, the bias becomes more pronounced: more options are being mispriced, and the mispricing is larger.

Graph 6 and 7 present the mispricing by the skewness and kurtosis adjusted model during the 10% lowest (6) and 10% highest (7) days of uncertainty. Although mispricing increases under high political uncertainty, especially for near at-the-money options, the impact is less pronounced compared to the Black-Scholes model. Especially deep out- and in-the-money options are less affected by uncertainty compared to Black-Scholes.

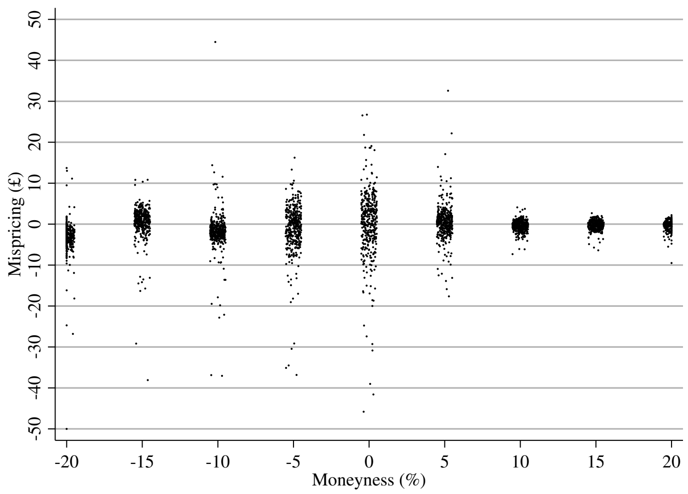
Hypothesis 3 is confirmed. The difference between the mispricing generated by the Black-Scholes model and the skewness and kurtosis adjusted model is increasing in political uncertainty and most notable for deep-in-the-money call options.



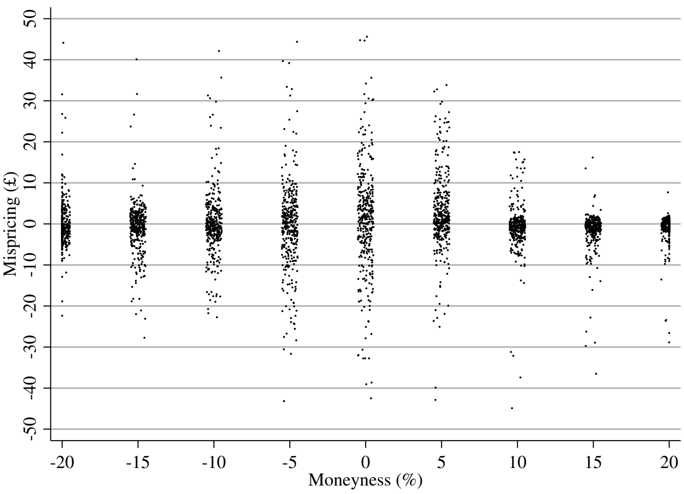
Graph 4: Black-Scholes Option Mispricing and Moneyness under Low Political Uncertainty



Graph 5: Black-Scholes Option Mispricing and Moneyness under High Political Uncertainty



Graph 6: Gram-Charlier Option Mispricing and Moneyness under Low Political Uncertainty



Graph 7: Gram-Charlier Option Mispricing and Moneyness under High Political Uncertainty

Trading Simulation Results

Using the two different trading strategies, "Max" and "Division," the achieved returns of both pricing models are first presented. The trading results are presented in Tables 6 and 7. The mean moneyness is calculated as the average level of moneyness of options contracts traded every day. The mean daily trades are the average number of options traded per trading day. In total, nine different contracts are available each day (corresponding to each level of moneyness).

The Sharpe ratio is calculated as the mean excess return, vis a vis the 12-month LIBOR rate, divided by the daily standard deviation. Sharpe ratios are annualized by multiplying the daily ration by the square root of the annual number of trading days (252). The Adjusted Sharpe Ratio is adjusted for skewness and kurtosis in the trading returns (Pezier and White, 2008):

$$Adjusted\ Sharpe\ Ratio = Sharpe\ Ratio * \left(1 + \frac{Skewness}{6} * Sharpe\ Ratio - \left(\frac{Kurtosis - 3}{24}\right) * Sharpe\ Ratio^2\right)$$

The Division trading strategy has similar trading results under both pricing models when no trading costs are used. When trading costs are introduced, the returns of the Black-Scholes model deteriorates, while the skewness and kurtosis adjusted model performs slightly better. In the no transaction cost base case, the difference between the two models is only 0.04%. In the 12.5 pence scenario, it increases to 2.57%. As a result, under both the 5 and 12,5 pence round-trip trading costs, the Gram-Charlier model performs significantly better.

When transaction costs are introduced, less expected profitable trades are identified, reflected in a lower number of mean daily trades. However, the trades which are expected to be profitable, turn out to be more profitable for the Gram-Charlier model and less profitable for the Black-Scholes model, resulting in the diverging performance difference. Trading costs seem to act as a barrier to prevent trades in option contracts when small price changes are expected. However, the notion that cheap out-of-the-money contract are less desirable trade targets is not confirmed based on the average level of moneyness remaining almost constant under all levels of transaction costs.

The average level of moneyness of the contracts traded does differ between both pricing models. The Black-Scholes model, on average, traded in more out-of-the-money options, while the Gram-Charlier traded in at-the-money contracts.

The Division strategy has positively skewed returns and excess kurtosis under both pricing models. Because the Adjusted Sharpe Ratio rewards positive skewness and punishes excess kurtosis, no significant difference if found with the regular Sharpe ratio as the two opposing forces cancel out. Overall, most risk-adjusted returns under the Divided strategy are low or negative. Only the theoretical long-short return, which goes short in the Black-Scholes model and long in the Gram-Charlier model, has a high risk-adjusted return of 1.99.

The Max strategy shows mostly similar results. The main difference is the higher performance compared to the Division strategy under the no transaction cost scenario for both pricing models. However, when transaction costs are introduced, the returns deteriorate rapidly. The mean returns of both models do not significantly differ under the Max strategy.

In general, it is possible to make profitable trading returns using both option pricing models when no transaction costs are incurred. However, when transactions cost increase to medium or high levels, only the Gram-Charlier model yield positive returns under specific trading rules.

Tabel 6: Summary statistics trading results strategy Division

Pricing model	Mean Moneyness (K/S)	Mean daily trades	Mean Daily Profit (%)	Daily Standard Deviation (%)	Skewness	Kurtosis	Annualized Sharpe Ratio	Adjusted Annualized Sharpe Ratio
				No Transaction Cost				
Black-Scholes	106.23	2.06	0.14%	31.96%	0.76	9.49	0.07	0.07
GC	99.79	2.60	0.18%	20.90%	0.91	11.72	0.13	0.13
Return Difference (GC-BS)			0.04%	20.24%	-0.12	10.42	0.03	0.03
				5 p. Round-Trip Transaction Cost				
Black-Scholes	106.23	2.04	-0.84%	31.98%	0.73	9.40	-0.42	-0.42
GC	99.77	2.55	0.22%	21.09%	0.96	11.73	0.16	0.16
Return Difference (GC-BS)			1.06% **	20.20%	-0.10	10.68	0.83	0.83
				12.5 p. Round-Trip Transaction Cost				
Black-Scholes	106.24	2.01	-2.34%	32.20%	0.70	9.59	-1.16	-1.15
GC	99.80	2.45	0.22%	21.20%	0.94	11.61	0.16	0.16
Return Difference (GC-BS)			2.57% ***	20.36%	0.06	10.78	2.00	1.99

Note: the significane level of the difference in return is indicated with **p< 0.05, ***p<0.01. The trading simulation was performed using price data between 25-11-2005 and 08-05-2020

Tabel 7: Summary statistics trading results strategy Max

Pricing model	Mean Moneyness (K/S)	Mean daily trades	Mean Daily Profit (%)	Daily Standard Deviation (%)	Skewness	Kurtosis	Anualized Sharpe Ratio	Adjusted Annualized Sharpe Ratio
				No Transaction Cost				
Black-Scholes	107.50	0.93	0.92%	45%	0.36	9.16	0.32	0.32
GC	105.84	0.98	0.57%	38%	0.79	9.47	0.24	0.24
Return Difference (GC-BS)			-0.35%	33.72%	0.76	13.10	-0.17	-0.17
				5 p. Round-Trip Transaction Cost				
Black-Scholes	107.46	0.92	-0.52%	45%	0.29	9.28	-0.19	-0.19
GC	105.75	0.98	-0.70%	38%	0.70	9.53	-0.30	-0.30
Return Difference (GC-BS)			-0.18%	33.57%	0.70	12.95	-0.10	-0.10
				12.5 p. Round-Trip Transaction Cost				
Black-Scholes	107.43	0.92	-2.79%	45%	0.20	9.34	-1.00	-1.00
GC	105.62	0.97	-2.36%	37%	0.54	9.25	-1.00	-0.99
Return Difference (GC-BS)			0.43%	33.40%	0.64	12.57	0.21	0.21

Note: the significane level of the difference in return is indicated with **p< 0.05, ***p<0.01. The trading simulation was performed using price data between 25-11-2005 and 08-05-2020

Economic Significance

A simple regression was made using political uncertainty as an independent variable, and the difference in daily trading returns realized by both pricing models as the dependent variable. Table 8 presents the obtained results. Even though the model has little explanatory power, there are significant positive relations between political uncertainty and Gram-Charlier pricing outperformance. Whereas the Division strategy as a whole yielded higher returns using the skewness and kurtosis adjusted model, compared to Black-Scholes, the Max strategy has higher outperformance when political uncertainty becomes high. The constants of the Max strategies under transaction costs are significant and negative, indicating that under low political uncertainty, the Black-Scholes model performs equally good or better.

When political uncertainty is low, and transaction costs are induced, the Division strategy already has some outperformance, indicated by the significant coefficient of 1.49%. When uncertainty increases, the expected outperformance increases with 0.34% per day for each 100-point increase in the uncertainty index. The level of transaction cost does not seem to deteriorate the effect of political uncertainty on the trading outperformance in both strategies.

Overall, political uncertainty appears to be an important or at least highly correlated to an important factor in options trading. When political uncertainty is low or at a medium level, it is possible to outperform the Black-Scholes pricing model only when there are transaction costs and using a diversified strategy. When political uncertainty is high, it is possible to outperform the Black-Scholes model both using a diversified strategy or by picking one "winner" contract each day.

The main difference between statistical significance and economic significance is the real-world presence of transaction costs. The results confirm Hypothesis 4: the trading performance difference between the skewness and kurtosis adjusted option pricing model, and the Black-Scholes model is increasing in political uncertainty. Introducing transaction costs does not change these results; instead, it enlarges the difference, underlining the robustness.

Table 8: Regression results of Political Uncertainty on Difference in Model Trading Performance

	Devide Strategy			Max Strategy		
Variable	No cost	0.05	0.125	No cost	0.05	0.125
Uncertainty (x100)	0.36**	0.33*	0.34**	0.42	0.63**	0.73***
	(0.17)	(0.17)	(0.17)	(0.28)	(0.28)	(0.27)
Constant	-1.11*	0.04	1.49**	-1.67	-2.15**	-1.87*
	(0.62)	(0.62)	(0.63)	(1.04)	(1.03)	(1.03)
Observations	3770	3770	3770	3770	3770	3770
R-squared	0.00	0.00	0.00	0.00	0.00	0.00

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Discussion

The observed Black-Scholes pricing bias is in line with the bias originally documented by MacBeth and Mervillie (1979). In-the-money options are underpriced, and out-of-the-money options are overpriced. These results are in contrast to Black (1975) and Corrado and Su (1996) & (1997), who find Black-Scholes overprices out-of-the-money call options. Nevertheless, the general observation that the Black-Scholes pricing model has some pricing bias related to option moneyness confirms a vast body of literature on the volatility smile and justifies the further exploration of non-normality.

The first regression result showed that the mispricing of the Black-Scholes model is positively related to political uncertainty. On days where the political uncertainty index has a higher value, the mispricing bias is enlarged. In-the-money call options are even more underpriced, and out-of-the-money call options are more overpriced compared to low uncertainty days. Compared to Kelly et al., (2016), similar results are found. Kelly at al., found that out-of-the-money put options become more expensive under political uncertainty. Assuming put-call parity holds, these findings imply that in-the-money call options should become more expansive, which is reflected by the findings of this paper.

By testing, if the Black-Scholes mispricing is affected by political uncertainty, two questions were answered. The first being, if there is a political risk premium in option prices. Second, if the Black-Scholes model is able to price the premium correctly. The evidence supports the notion that investors are willing to pay a premium for protection against adverse political shocks. The increased mispricing also suggests that the Black-Scholes model is inappropriate to capture investors' preference for these protective options when uncertainty is high.

In the second step, the relation between skewness and kurtosis, and political uncertainty was analyzed. The obtained Black-Scholes mispricing pattern suggests that political uncertainty is associated with negative skewness. The relation between political uncertainty and kurtosis was not inferred from the Black-Scholes mispricing pattern. Reason being that the effect of non-normal kurtosis on option prices is symmetric to both in- and out-of-the-money options.

Existing literature also suggested that political uncertainty was related to return distributions with negative skewness and excess kurtosis (Corrado and Su, 1997) and (Kelly at al, 2016). Surprisingly, the results show that skewness is positively related to political uncertainty. Even though the economic significance was low, these findings contradict the beliefs formed based on the literature and mispricing patterns. Meanwhile, the tests of Hypothesis 2 revealed that more negative levels of skewness are related to increasing political uncertainty, while kurtosis is not related to changing levels of political uncertainty.

Apart from the relation between the values of skewness and kurtosis and changes in political uncertainty, the distribution of the Political Uncertainty Index values is also related to skewness and kurtosis. The most negative values of skewness are accompanied by both far below and far above average values of political uncertainty, and more extreme high values. These results suggest that the relation between expected returns and political uncertainty is not as straightforward to capture in a simple regression.

A part of an explanation could be found based on Pástor and Veronesi (2013). Financial markets react to political shocks by changing their view on future government policy. As a result, option prices react to changing uncertainty. Meanwhile, as the asset market assimilates the political shock by adapting the asset prices, some of the uncertainty within the market is resolved. As uncertainty in financial markets is resolved, expected returns normalize while the political uncertainty index, based on newspaper attention, remains high.

Another explanation could be an omitted variable. The importance of economic conditions was not directly tested in relation to the political uncertainty premium. Pástor and Veronesi (2013) find that the effect of political shocks is larger when economic conditions are poor because government policies are more likely to be replaced. It is likely that economic conditions were reflected in the Economic Policy Uncertainty Index used, as newspaper attention for economic topics is intensified during poor economic times. Although the results are robust without controlling for economic circumstances, future research could analyze the effect of economic conditions on the political risk premium pricing.

For political uncertainty premium to be priced via non-normality, no stable relation with skewness and kurtosis is needed. The fact that expected return distributions are non-normal and related to political uncertainty justifies the use of the Gram-Charlier model in capturing the political risk premium. Evidence is provided that there is a relation between implied levels of non-normality and political uncertainty. However, the exact dynamics could be a topic of future research.

In the last part of the statistical analysis, the political uncertainty index was regressed on the decrease in mispricing after controlling for skewness and kurtosis. When political uncertainty is high, the adjusted pricing model outperforms the Black-Scholes model more compared to low uncertainty. These results indicate that non-normality, in whichever form, plays a significant role in pricing in the political risk premium.

By adjusting the Black-Scholes pricing model to include skewness and kurtosis, it is possible to capture at least a part of the political risk premium. Although it remains unclear how exactly the return distributions change when political uncertainty is high, the Gram-Charlier pricing model is able to capture these changes better than the classic Black-Scholes model. Especially options that provide protection against extreme downward price movements, most associated with political uncertainty, benefit the most from the skewness and kurtosis adjustment.

Using two trading strategies with different levels of transaction costs, the economic significance of using skewness and kurtosis was tested. Although it is possible to outperform the trading results of the Black-Scholes pricing model using the skewness and kurtosis extension during periods of low political uncertainty, the differences increased significantly when political uncertainty increased. The introduction of transaction costs seemed to promote the divergence of trading returns. These results stress that adjusting for skewness and kurtosis is much more than an academic exercise. Practitioners can benefit from explicitly introducing non-normality into option pricing models. Solely relying on the intuition that out-of-the-money put options are more expansive could be insufficient when the relation between non-normality and political uncertainty is unstable.

The most important contribution of this paper is not to show that Black-Scholes is inadequate in pricing options during politically uncertain times. The effect of non-normal expected returns on option prices does make the lognormal Black-Scholes model incapable of correctly pricing the political risk premium. Instead, the contribution of this paper is to show that there is a mechanism in the options market that prices political uncertainty, and by extending the Black-Scholes model, it is possible to capture this mechanism.

The advantages of pricing in political uncertainty using the Gram-Charlier approach, as compared to any Black-Scholes manipulation, are twofold. First, the assumption that volatility is a characteristic of an asset is not violated. By allowing non-normality to exist, a large part of the inconvenience created by the lognormal assumption of Black-Scholes is prevented. Second, complementary to the intuition and empirical proof that option prices react to political uncertainty, the skewness and kurtosis adjusted pricing model is unique in providing a fundamental pricing method that can connect both intuition and empirical proof.

Another contribution is made by using an extensive dataset of FTSE 100 option prices combined with a daily political uncertainty measure. Whereas previous studies on non-normality in options or political uncertainty mainly examined short time frames (Corrado and Su, 1997) or explicit political events (Kelly at al., 2016), this paper analyzed a prolonged time frame with a total of more than 31 thousand different observations. The result is a comprehensive understanding of how option prices reflect political risk.

A further implication of this paper is the confirmations of the findings by Corrado and Su (1997): superior options price estimates can be obtained using the skewness and kurtosis adjusted pricing model. It leaves to question why non-normality is not part of the mainstream option pricing theory. Arguably the extra steps necessary to estimate option prices could pose a barrier. However, from a practitioner's perspective, the extra steps would only require a single set up of the model. Another reason preventing the general breakthrough of non-normality could be the existence of an alternative superior pricing model, possibly based on unrealistic assumptions.

Limitations & Further Recommendations

The main shortcoming of this paper is the limited number of daily price observations and the lack of actual bid-ask spreads. Although many prices were collected, each day consisted of only nine observations. Included in the analysis are options with rather extreme levels of moneyness (20% in- and out-of-the-money). As the liquidity of these contracts can be doubtful, it is not impossible that some outliers affected the implied return distribution parameters. Future research could repeat the analysis and focus on mispricing relative to bid-ask boundaries, as applied by Corrado and Su (1997).

Another limitation is the fact that all option prices had the same maturity. Although this is convenient for processing the data, it prevents the actual observation of price changes of contracts form one day to the other when applied in a trading strategy. A more precise picture of the economic significance of the findings can be created by observing price developments of single contracts.

Conclusion

This paper examined the pricing of the political uncertainty risk premium in FTSE 100 index call options between 2005 and 2020, through skewness and kurtosis in expected return distributions. Implied values of volatility, skewness, and kurtosis were estimated using a simultaneous equation procedure. First, it was established if there was a political risk premium by comparing Black-Scholes pricing estimates to observed option prices. Especially the deep-in-the-money call option is prone to mispricing under political uncertainty, suggesting that there is a political risk premium not captured by the Black-Scholes model.

The second step examined the relation between skewness and kurtosis and political uncertainty. The mean level of political uncertainty is positively related to both skewness and kurtosis. Also, skewness is negatively related to increasing political uncertainty. Moreover, the level of political uncertainty tends to more volatile, higher skewed, and more leptokurtic when market skewness is below the median.

The final step compared the mispricing of both the Black-Scholes pricing model and the skewness and kurtosis adjusted model vis a vis political uncertainty. The difference in absolute mispricing of both pricing models is increasing in political uncertainty, indicating that non-normality plays a role in pricing in political uncertainty in options. The results remain robust when tested out-of-sample in a simulated trading strategy, including transaction costs. Future research recommendations include further examination of the relation between skewness, kurtosis, and political uncertainty. Also, the analysis could benefit from the use of actual bid-ask spreads and more daily option contracts.

Appendix: References

Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring Economic Policy Uncertainty*. *The Quarterly Journal of Economics*, *131*(4), 1593–1636. https://doi.org/10.1093/qje/qjw024

Black, F. (1975). Fact and Fantasy in the Use of Options. *Financial Analysts Journal*, *31*(4), 36–41. https://doi.org/10.2469/faj.v31.n4.36

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, *31*(3), 307–327. https://doi.org/10.1016/0304-4076(86)90063-1

Brown, C. A., & Robinson, D. M. (2002). Skewness and Kurtosis Implied by Option Prices: A Correction. *Journal of Financial Research*, *25*(2), 279–282. https://doi.org/10.1111/1475-6803.t01-1-00008

Cont, R., & da Fonseca, J. (2002). Dynamics of implied volatility surfaces. *Quantitative Finance*, *2*(1), 45–60. https://doi.org/10.1088/1469-7688/2/1/304

Corrado, C. J., & Su, T. (1996). SKEWNESS AND KURTOSIS IN S&P 500 INDEX RETURNS IMPLIED BY OPTION PRICES. *Journal of Financial Research*, *19*(2), 175–192. https://doi.org/10.1111/j.1475-6803.1996.tb00592.x

Datastream. (13-5). [FTSE 100 Index option data]. Refinitiv. http://product.datastream.com/browse/Search.aspx?AppGroup=DSAddin

Economic Policy Uncertainty Index. (2020, May 13). [Dataset]. https://www.policyuncertainty.com

Emanuel, D. C., & MacBeth, J. D. (1982). Further Results on the Constant Elasticity of Variance Call Option Pricing Model. *The Journal of Financial and Quantitative Analysis*, *17*(4), 533. https://doi.org/10.2307/2330906

Ferreira, E., Gago, M., & Rubio, G. (2003). A semiparametric estimation of liquidity effects on option pricing. *Spanish Economic Review*, *5*(1), 1–24. https://doi.org/10.1007/s101080300058

Gonçalves, S., & Guidolin, M. (2006). Predictable Dynamics in the S&P 500 Index Options Implied Volatility Surface*. *The Journal of Business*, *79*(3), 1591–1635. https://doi.org/10.1086/500686

Heston, S. L. (1993). A Closed-Form Solution for Options with Stochastic Volatility with Applications to Bond and Currency Options. *Review of Financial Studies*, *6*(2), 327–343. https://doi.org/10.1093/rfs/6.2.327

Jackwerth, J. C. (1999). Option-Implied Risk-Neutral Distributions and Implied Binomial Trees. *The Journal of Derivatives*, *7*(2), 66–82. https://doi.org/10.3905/jod.1999.319143

Jarrow, R., & Rudd, A. (1982). Approximate option valuation for arbitrary stochastic processes. *Journal of Financial Economics*, *10*(3), 347–369. https://doi.org/10.1016/0304-405x(82)90007-1

Kelly, B., Pastor, L., & Veronesi, P. (2016). The Price of Political Uncertainty: Theory and Evidence from the Option Market. *The Journal of Finance*, *71*(5), 2417–2480. https://doi.org/10.1111/jofi.12406

MacBeth, J. D., & Merville, L. J. (1979). An Empirical Examination of the Black-Scholes Call Option Pricing Model. *The Journal of Finance*, *34*(5), 1173–1186. https://doi.org/10.1111/j.1540-6261.1979.tb00063.x

Officer, R. R. (1973). The Variability of the Market Factor of the New York Stock Exchange. *The Journal of Business*, *46*(3), 434. https://doi.org/10.1086/295551

Pástor, Ľ., & Veronesi, P. (2013). Political uncertainty and risk premia. *Journal of Financial Economics*, *110*(3), 520–545. https://doi.org/10.1016/j.jfineco.2013.08.007

Pézier, J., & White, A. (2008). The Relative Merits of Alternative Investments in Passive Portfolios. *The Journal of Alternative Investments*, *10*(4), 37–49. https://doi.org/10.3905/jai.2008.705531

Rachev, S. T., Fabozzi, F. J., & Menn, C. (2005). *Fat-Tailed and Skewed Asset Return Distributions : Implications for Risk Management, Portfolio Selection, and Option Pricing* (1st ed.). Wiley.

Rubinstein, M. (1985). Nonparametric Tests of Alternative Option Pricing Models Using All Reported Trades and Quotes on the 30 Most Active CBOE Option Classes from August 23, 1976 through August 31, 1978. *The Journal of Finance*, *40*(2), 455–480. https://doi.org/10.1111/j.1540-6261.1985.tb04967.x

Skiadopoulos, G., Hodges, S., & Clewlow, L. (2000). The Dynamics of the S&P 500 Implied Volatility Surface. *Review of Derivatives Research*, *3*(3), 263–282. https://doi.org/10.1023/a:1009642705121

Whaley, R. E. (1982). Valuation of American call options on dividend-paying stocks. *Journal of Financial Economics*, *10*(1), 29–58. https://doi.org/10.1016/0304-405x(82)90029-0