Norges Handelshøyskole

FIN11 Trading and Market Microstructure

FIN11 Term paper

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Final Term Paper

Coffee Price:
Influencing Factors and Hedging Strategies

NHH – Norwegian School of Economics



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Abstract

This paper aims to identify factors influencing the coffee spot price and to determine opportunities for hedging against changes in the spot price. To accomplish this, the structure of the coffee market, on both the producer and consumer side, is closely examined. In the following, elements to explain the volatility of the global coffee market are revealed. Brazil is the largest producer of the most used coffee bean Arabica. To analyse the impact of weather in the main Brazilian cultivation on the coffee price, a regression is conducted. Subsequently, a weather simulation for four quarters is run, and different hedging strategies are applied to manage the risk of coffee price changes for a major coffee chain.

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1. Introduction

Consumers might soon experience a surge in green coffee prices since coffee spot prices are up around 80% compared to last year (Shunev, 2021; Hamer & Terazono, 2021). The principal reason for surging prices is a series of environmental events in the coffee-nation of Brazil (Shunev, 2021; Hamer & Terazono, 2021). Coffee - as an agricultural good - is exposed to weather conditions affecting the production yield and consequently the spot price. Thus, hedging the resulting price risk is of high importance for companies in the industry, as the cost of coffee greatly influences their bottom-line profit. Hedging the price risk can be achieved in various ways, one of them being via financial instruments, such as derivatives.

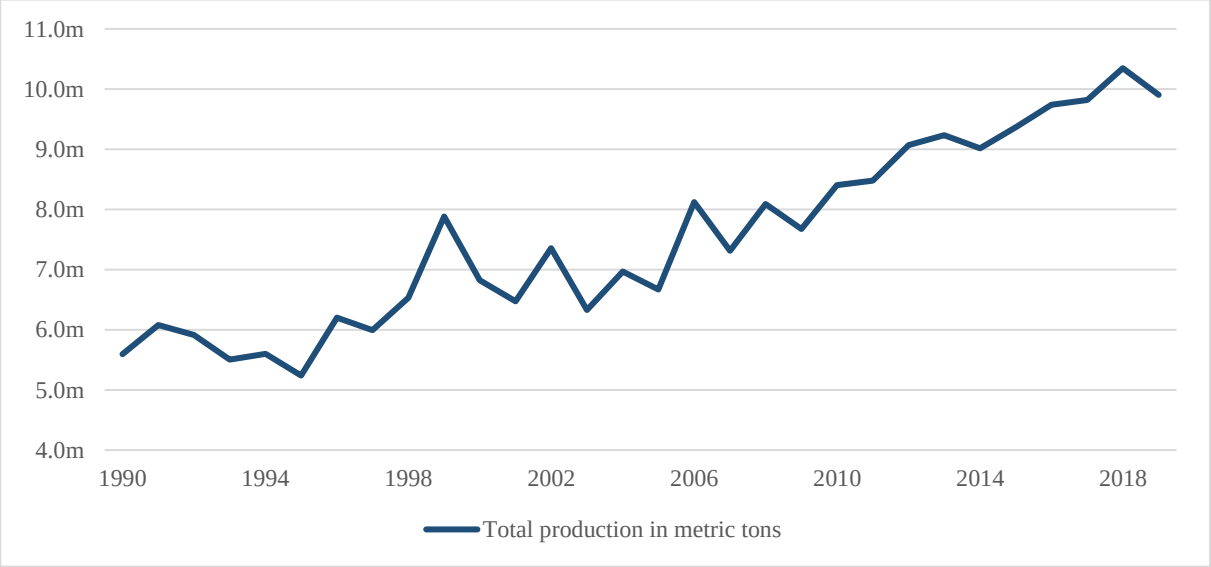
To understand the coffee market and its price risk, one needs to understand the producer and consumer market first. Whilst there is a large variety of coffee plants, only two are used for commercial use: Arabica and Robusta. Coffea Arabica originates from Ethiopia and is primarily cultivated in Latin America, Africa, Southeast Asia, and China (Costa Freitas & Mosca, 1999). Coffea Robusta originally grew on the opposite side of Africa (Côte d'Ivoire), but is now commonly planted in Vietnam and Africa (Costa Freitas & Mosca, 1999). The coffee market is valued at $409.90 billion in 2021 (Statista, 2021), which is 56.9% attributable to Arabica and 43.1% to the less palatable but cheaper Robusta (ICO, 2020).

The markets for Arabica and Robusta are thoroughly separated on the C Market (Central Market) (Sustainable Harvest Coffee Importers, 2021). The C Market was established in 1968 by producers in Central America to have a separate Arabica market (Sustainable Harvest Coffee Importers, 2021). Later, the C Market was incorporated into the NYSE for worldwide trade and is operated by the Intercontinental Exchange, ICE (Intercontinental Exchange, Inc, 2021; Sustainable Harvest Coffee Importers, 2021). For the sake of uniform quality of the commodity, specific requirements need to be met to have a trading allowance, i.e., unroasted Arabica bean that was produced in one of 20 predetermined countries and exchanged in one of eight warehouses with a minimum quantity of 37,500 lbs (app. 17 metric tons). The C Market not only allows for physical trade in the bean (the so-called spot market) but also facilitates the futures market. Futures are agreements between buyers and sellers to trade specific quantities at specific points in time. Here, the ICE acts as a dealer providing liquidity and immediacy to buyers and sellers (Sustainable Harvest Coffee Importers, 2021).

1.1 Producer Market

The producer market consists of farmers producing and selling coffee beans to roasters and wholesalers. The largest producers of coffee are Brazil (39.4% of total production, mostly Arabica) and Vietnam (17% of total production, mostly Robusta) (FAO, 2021). Roughly 80% of the coffee is produced by around 25 million smallholders (Fairtrade, 2021) located in the coffee belt, which is the land around the equator that is suitable for coffee cultivation. Due to the stringent requirements of the C Market, there is little to no room for product differentiation. With this homogenous product and a high number of suppliers, the market has the characteristics of a perfect competition where all suppliers are price takers (Carlton & Jeffrey, 2005, pp. 81-84). This means that the cost of bad harvests cannot be passed on to the buyer. Despite the inherent risk of farming coffee and the intense competition in the market, the production has risen steadily over the past 30 years with an average yearly increase of 2.6% (in total, 77.0%).

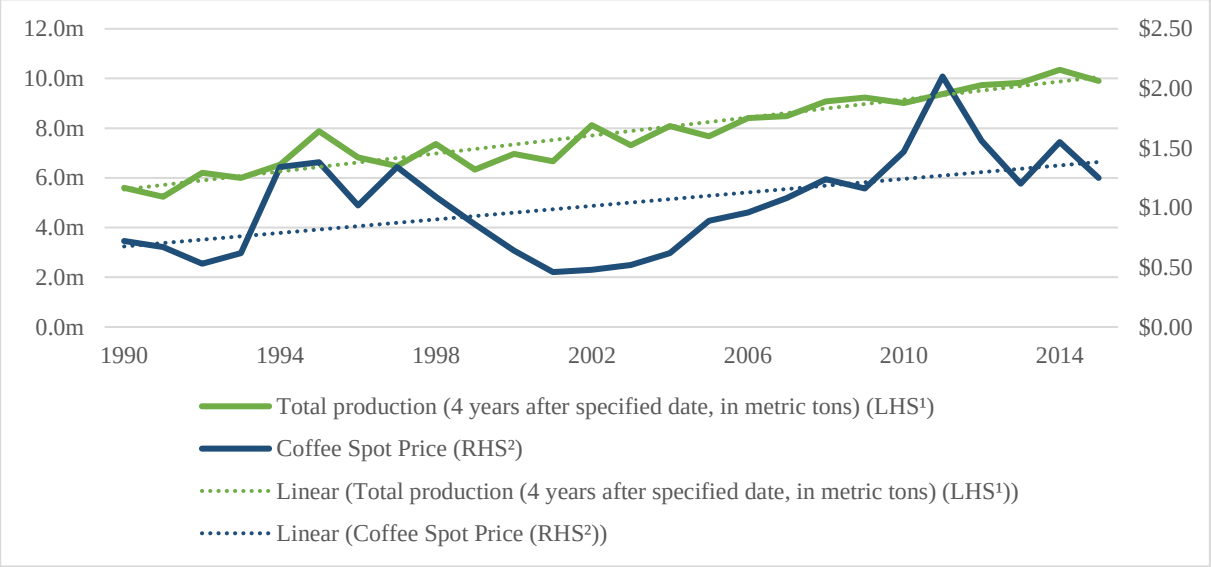
Figure 1: Total Coffee Production



Source: ICO 2021

An increase in price induces an increase in volume, which becomes evident as both the coffee spot price and the total production follow the same upward trend. A coffee plant takes four years to mature on average, meaning changes in output should only be visible four years after a price increase. By comparing the coffee spot prices with the total production delayed by four years, a regression analysis proves an R-squared of 38% and a coefficient of 2,200,790. In theory, the total production should increase by 2.2 million metric tons four years after the spot price of coffee increases by $1.

Figure 2: Coffee Spot Price and Total Production



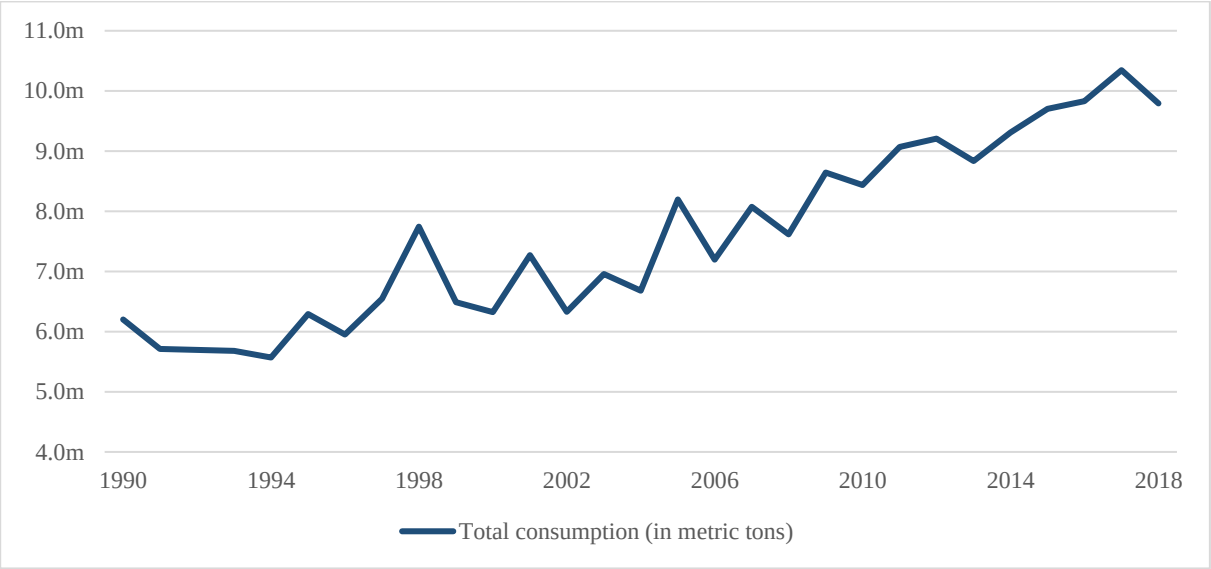
Source: ICO 2021

1.2 Consumer Market

The consumer market consists of two types of businesses. The first type are businesses buying directly from producers and wholesalers and then distributing the coffee to end-consumers. The second type are vertically integrated businesses that farm beans themselves and sell the coffee directly to the end-consumer. Although they are less affected by volatility in market prices, their plantations are exposed to the same yield affecting factors as farmers (Goldstein, 2018). Like the production, the demand for coffee has risen steadily over the last 30 years, with an average yearly increase of 2.5% during the past 30 years (ICO, 2021).

[1] LHS = Left hand side
[2] RHS = Right hand side

Figure 3: Total Coffee Consumption[3]



Source: ICO 2021

The consumer market is segmented into coffee shops and roasted coffee beans for home use. Firms active in the consumer market face monopolistic competition in both of these segments (Bartleby Research, 2020; O'Connor, 2016, p. 18). Coffee shops offer similar products but create differentiated coffee experiences. The market for roasted coffee beans for home use is characterised by a variety of slightly differentiated products (whole-bean, ground coffee, instant coffee, coffee pods, and capsules).

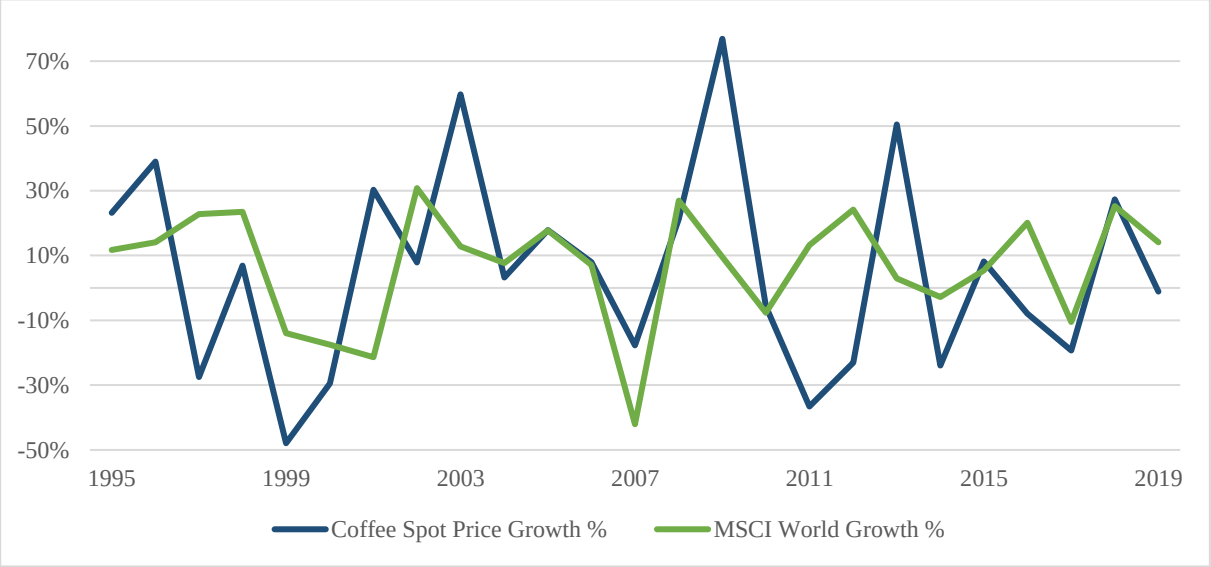
With the producer and consumer market defined, we can proceed to analyse the coffee price to quantify the need for market participants to hedge price-related risk.

1.3 Coffee Price Analysis

To see if the development of the coffee spot price is connected to the broad development of equity prices, we choose the MSCI World Index (MSCI WI) as a benchmark, as it is one of the broadest equity indexes representing 1,555 stocks over 23 developed countries (MSCI, 2020). When benchmarking the spot price with the MSCI WI over 25 years, a significant mismatch becomes apparent: while the MSCI WI appreciated by +266% over the period, the coffee spot price shows a mere gain of +35%. Commodities like coffee are known for persistent and increased volatility, often underlying quarterly swings of 11% to 90% (Hecht, 2021). In fact, over the 25-year period displayed in figure 4, coffee proves to be twice as volatile (σ = 32.3%) as the MSCI World (σ = 16.8%).

[3] Consumption = production ± change in inventory

Figure 4: Year on Year Growth in Coffee Spot Price and MSCI WI



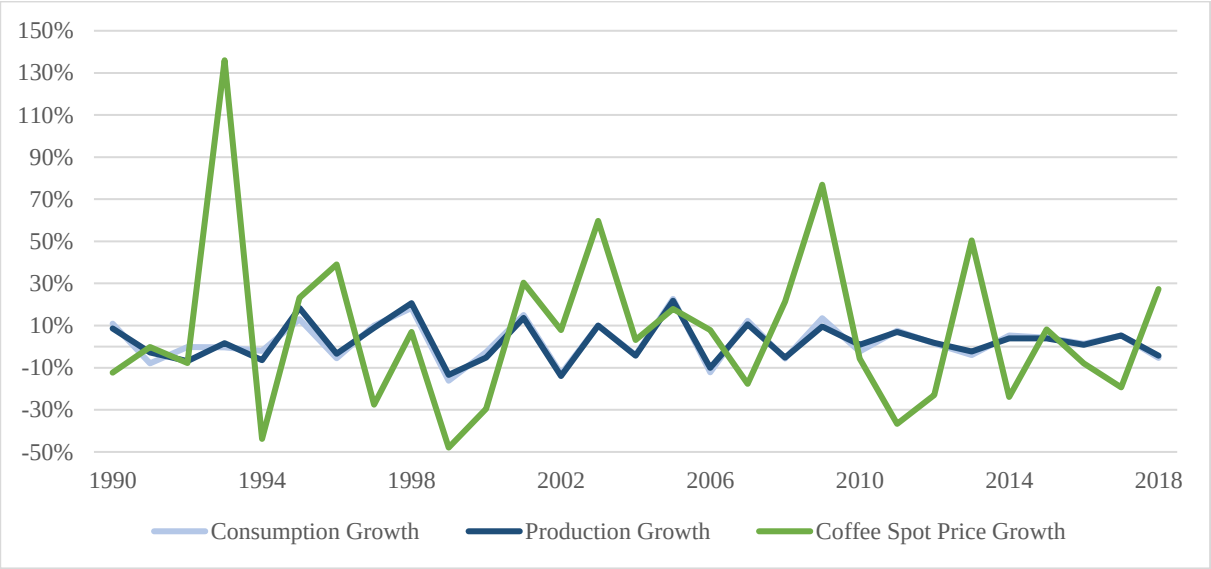
Source: ICO 2021, Onvista 2021

When searching for co-movements[4] of coffee with the MSCI ACWI, the commodity appears to be rather disconnected from the development of the benchmark over the last decade (this proves to be correct, showing a low degree in correlation, r = 0.268). Using more granular daily price data, a low covariance can be found (cov[coffee price, MSCI ACWI] = 0.015) between the MSCI WI and the spot price, meaning movements in the index do not trigger a similar change in the coffee price.

The low covariance can be explained by different price drivers of the index and the coffee spot price. While the MSCI WI is significantly driven by the worldwide economy, food and beverage markets are less impacted by it (ICO, 2009, p. 1). Hence, coffee is less affected by changes in the worldwide economy due to a relatively price inelastic demand and supply. The price elasticity of demand for coffee is -0.2 (Bettendorf & Verboven, 2000, p. 10), meaning an increase in price leads to a considerably smaller decrease in demand. The harvest volume is not adjustable in the short term since only one harvest takes place annually, and new coffee plants take four years to mature. Thus, the price elasticity of supply is perfectly inelastic over the short term (The supply and demand of coffee, 2018). Rather price inelastic supply and demand make coffee less vulnerable to macroeconomic setbacks and decrease co-movement with the MSCI World Index.

[4] Co-movement is the similar and correlated movement of securities.

Figure 5: Comparison of Consumption, Production, and Coffee Price



Source: ICO 2021

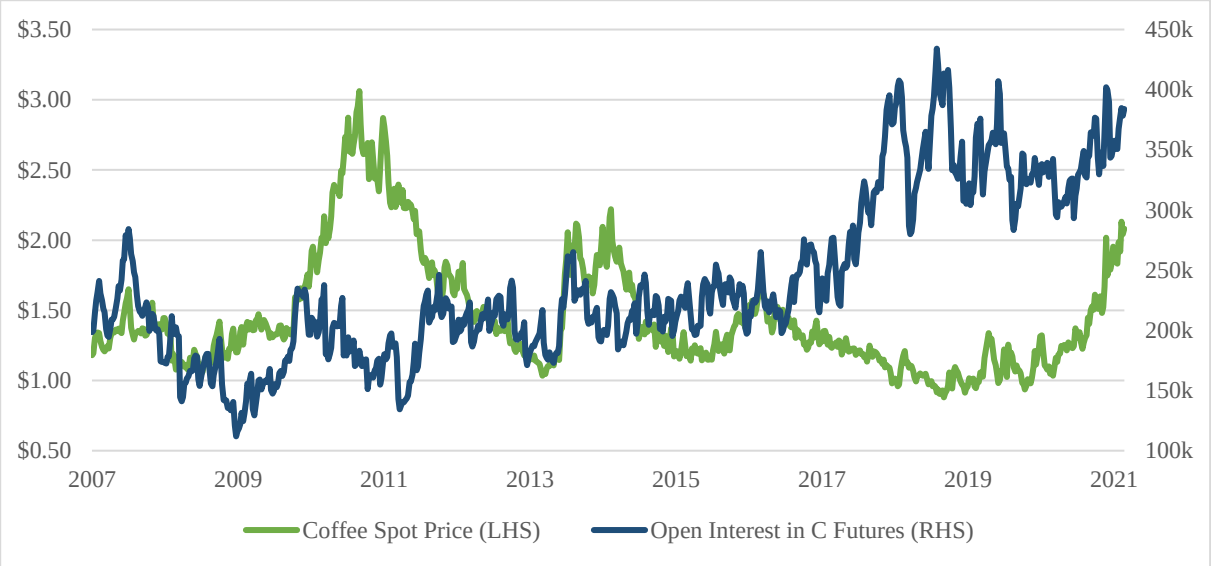
Based on economic theory, the factors influencing the price of a traded good are supply and demand. However, a regression with these variables only yields an R-squared of 17%, meaning that changes in annual production and consumption only partly explain movements in the coffee price. Consequently, there have to be other factors playing a more prominent role in price building. To determine these factors, we also analyse the impact of hedging and speculation and the impact of weather on the coffee price.

Hedging and speculation could influence the price building, as there is significant trade in derivatives on the commodity rather than in the commodity itself, which may distort prices. With the deregulation of financial instruments (also known as the financialization of the commodity market) in 2000 (Noemie & Junior, 2012, p. 31), commodity trading volume increased sharply, and many commodity prices rose and became more volatile (Chari & Christiano, 2017). This led to a 300% increase of the open interest[5] in the coffee market between 2000 and 2017 (Lordemann et al, 2021, p. 14), whilst the spot market increased by 44% over the same period. After a high during the financial crisis in March 2008 with 284,067 outstanding contracts, the futures market cooled down despite rising commodity prices. Open interest has been increasing over the last decade and peaked in March 2019 with approximately 50% more volume (434,125 open contracts) than during the financial crisis, which means that hedging and speculation in coffee increased significantly. The open interest is to 40%-60% attributable to

[5] Open interest is the sum of outstanding derivative contracts. Open interest indicates how active and liquid the market for the underlying is.

hedgers such as companies producing and buying coffee, and speculation accounts for 10-30% (Lordemann et al, 2021, p. 15).

Figure 6: Coffee Price and Open Interest



Source: ICO 2021, ICE 2021

Notably, the hedging positions have increased by approximately 25% since the start of 2019 what can be interpreted as an anticipation of price increases and hedging against these (Lordemann et al, 2021, p. 15). Noemie & Junior (2012, p. 32) concluded that due to the highly efficient futures market, distortions caused by hedging and speculation occur only in the short-term and are quickly balanced out with the spot market (Aulerich et al, 2014, pp. 245-247).

With 39.4% (FAO, 2021) of coffee being farmed in Brazil, the commodity's price highly depends on the Brazilian harvest volume, which in turn heavily depends on local weather conditions. Consequently, to determine what effect weather has on the coffee price, it makes sense to analyse this impact using data from Brazilian weather stations. Therefore, we use regressions to determine to what extent the coffee price can be explained by Brazilian weather.

2. The Impact of Brazilian Weather on the Coffee Price

Coffee requires distinct climatic circumstances to grow. These circumstances prevail in "the coffee belt", which covers countries between the Tropic of Cancer and the Tropic of Capricorn (Baskerville, 2017).

Arabica coffee beans are generally more sensitive to changes in climate than Robusta beans. Arabica beans grow most efficiently in regions near the equator at altitudes of 1100-1900

meters above sea level or in subtropical climate regions at altitudes of 550 – 1100 meters above sea level (Coffee Research Institute, 2006). The optimal temperature during the growing period is between 15-24 ºC. Higher temperatures reduce the photosynthetic power, while lower temperatures disrupt the metabolic process of the plants (Mattoon et al., 2021, pp. 5-7). Rainfall between 1,500 to 2,500 mm per year, as well as a relative humidity between 70 and 90%, are furthermore essential factors for a successful harvest. If all these favourable conditions are fulfilled, coffee can be harvested up to two times per year instead of only once (Coffee Research Institute, 2006).

Robusta coffee, in comparison, is grown at much lower altitudes of up to 600 meters above sea level and can thrive in temperatures of up to 26 ºC. When it comes to climatic conditions, the bean is far less sensitive than the Arabica variety (Institute for scientific information on coffee, 2021). It takes around 6 to 8 months before Arabica coffee can be harvested. Robusta coffee matures in 9 to 11 months (Piening & Kowalschik, 2016).

2.1 Quantifying the Impact of Brazilian Weather on Coffee Spot and Futures Prices

The subsequent analysis aims to derive the impact of a variety of meteorological factors on the yield of coffee farms in Brazil. The total market share of 39.4% makes the country the most influential coffee producer globally, which is why the coffee spot price and futures prices are highly dependent on Brazilian harvest yields (FAO, 2021, p. 18). The analysis draws on weather data from Brazil's main coffee-producing regions (Paraná, São Paulo, Minas Gerais, and Espirito Santo). The chosen twelve weather stations (Avare, Barbacena, Carbonita, Formoso, Itamarandiba, Ituiutaba, Maraba, Paracatu, São Mateus, São João do Paraíso, Unai, and Vicose) provide daily data from 1961 until 2019 and serve as independent variables (Saraiva, 2019). The global historical coffee spot prices from the past 45 years and the US Coffee C Futures prices of the past 15 years feature as dependent variables (Macrotrends LLC, 2021; Fusion Media Limited, 2021). Using the average of the 12 stations' weather data allows for a more holistic picture of the overall meteorological situation in Brazil's coffee-growing regions. Since long-lasting weather changes have a more significant impact on the growth process of coffee than short-term changes, the weather data and the commodity and futures prices are averaged to a quarterly year basis. The influence of Brazilian weather on the global coffee spot price and coffee futures price is quantified in the upcoming regressions.

The regressions are based on an Ordinary Least Squares estimation model (OLS). The OLS method causes the sum of the estimated function to be the smallest possible due to the

squared variances (Rottmann, 2018). The effects of the independent variables on the spot price of the commodity can be calculated using the OLS regression equation:

Equation 1: OLS Regression Equation

$$y = \alpha + \beta 1x1 + \beta 2x2 + \beta 3x3 + \ldots + \beta kxk + \varepsilon$$

The variable "α" represents the constant of the regression equation. The coefficient of the variable "xk" (βk) measures the change of the dependent variable, given that βk increases by one unit. The factor "ε" symbolises the unobservable confounding variable, which cannot be explained by the regression equation. The current weather is influencing the value of the commodity in the future when it is harvested, which is why a lagged variable is used (this is not the case for futures, as plausible changes in the future coffee value are priced in immediately).

Only selected independent weather variables are used in both regressions. They are covering the fields precipitation per day in mm, the wind speed in m/s, the cloudiness in tenth, the minimal and maximal temperature in ºC, the relative humidity in percent, the "Piche" evaporation in mm, and the atmospheric pressure measured in mbar (all averaged on a quarterly year base). These factors are the most significant for a successful coffee harvest (Jaramillo et al., 2011, pp. 2-4; Mendesil & Tesfaye, 2009, p. 203).

The dependent variable of our first regression is the global commodity spot price of coffee in US Dollars per pound. To realise the delay between growing coffee and selling it, a lag of three quarters is used, as it takes up to six months to harvest the coffee cherries and three months to dry and process them, making them ready to be exported (Longbottom Coffee and Tea, 2018). The results of the two regressions are sorted from the greatest positive impact to the greatest negative impact on the dependent variable. All information (coefficients, standard deviations, levels of significance, number of observations, and R-values) are summarised in table 1.

The 183 quarterly observations correlated for this regression yield an R-value of 14.09%. As outlined in table 1, the maximum temperature has the greatest positive (price increase) impact on the coffee spot price, with a coefficient value of 0.382. Consequently, rising temperatures evoke a price rise. Also, the "Piche" evaporation, an indicator of water loss due to evaporation, has a strong positive influence on the coffee spot price. Its value is the second largest with 0.350. The atmospheric pressure and the average relative humidity have a slightly positive effect on the price. Due to overall higher coefficients, the total influence of the negative coefficients is greater than the influence of positive coefficients. Precipitation negatively affects

the coffee spot price with a coefficient of -0.103. In other words, as the amount of rain increases, the price decreases. The wind speed has a coefficient of -0.176. The cloudiness has a coefficient of -0.345 and thus represents the second greatest negative influence on the coffee spot price. In contrast to the maximum temperature, the minimum temperature has the greatest negative influence on the price, with a coefficient of -0.483. It is important to note that only the results of cloudiness, minimal temperature, "Piche" evaporation and atmospheric pressure have a significance greater than 90%.

The dependent variable for the second regression is the US Coffee C Futures price in USD. For this variable, we use no lag, as futures secure the price of coffee in the future (Gorton & Rouwenhorst, 2006). The 55 matched observations yield a quality measure of 27.55%. Cloudiness has the greatest positive influence on future prices, with a coefficient of 97.23. The maximum temperature and the "Piche" evaporation also have a positive effect on the prices with coefficients of 25.60 and 22.29, respectively. The futures prices are slightly negatively influenced by precipitation and relative humidity with coefficients of -1.87 and -5.96, respectively.

Furthermore, the atmospheric pressure has a negative influence on futures prices, with a coefficient of -14.18. The minimum temperature and the wind speed have the greatest negative influence with coefficients of -70.15 and -186.41, respectively. The correlations are more than 90% significant in 5 out of 8 cases, as shown in table 1.

Table 1: Regression of Brazilian Weather Indicators and Global Coffee Spot Price

	Commodity price of coffee in USD/lbs lag 3	US Coffee C Futures price in USD
Precipitation	-0.103 (0.060)	-1.87 (18.260)
Wind speed	-0.176 (0.208)	-186.41 (97.893)*
Cloudiness	-0.345 (0.107)***	97.23 (57.709)**
Minimum temperature	-0.483 (0178)*	-70.15 (57.366)***
Maximum temperature	0.382 (0.204)	25.60 (62.377)
Relative humidity	0.023 (0.044)	-5.96 (15.503)
Piche evaporation	0.350 (0.155)**	22.29 (22.248)**
Station atmospheric pressure	0.053 (0.017)**	-14.83 (5.181)***
Observations	183	55
R-squared	0.1409	0.2755

Notes. *,**, and *** indicate that the corresponding p-values are less than 0.10, 0.05, and 0.01, respectively

2.2 Summary of the Weather Impact on Coffee Spot and Futures Prices

The regressions indicate that coffee spot prices are to 14.09% attributable to Brazilian weather and the coffee futures prices to 27.55%. The results for the futures prices exhibit not only a higher measure for quality but also a higher level of significance. This strengthens the evidential value of the regression. Especially, high and low temperatures seem to have a noticeable impact on the prices in both cases, since coffee plants, and in particular, Arabica coffee plants, require a constant temperature of between 15-24 ºC. The influence of rain seems to be rather small. Both extremes (high and low amounts of rain) are disadvantageous for coffee cultivation but may compensate each other. Cloudiness proves to be an essential factor for the price development of coffee. Observations by Kerkhoff (2019) confirmed this result. Direct solar radiation for more than 5 hours a day leads to too high evaporation, despite perfect amounts of precipitation (Kerkhoff, 2019). A good harvest, and thus also the commodity's spot price and futures prices, is therefore largely dependent on cloud coverage.

The analyses show that no single variable is influencing the price building of coffee to an unproportionally large extent, which is why hedging only one of them would not entirely eliminate the price risk. Since hedging all influencing factors individually is not only complicated but also inefficient, it makes more sense to hedge the price itself.

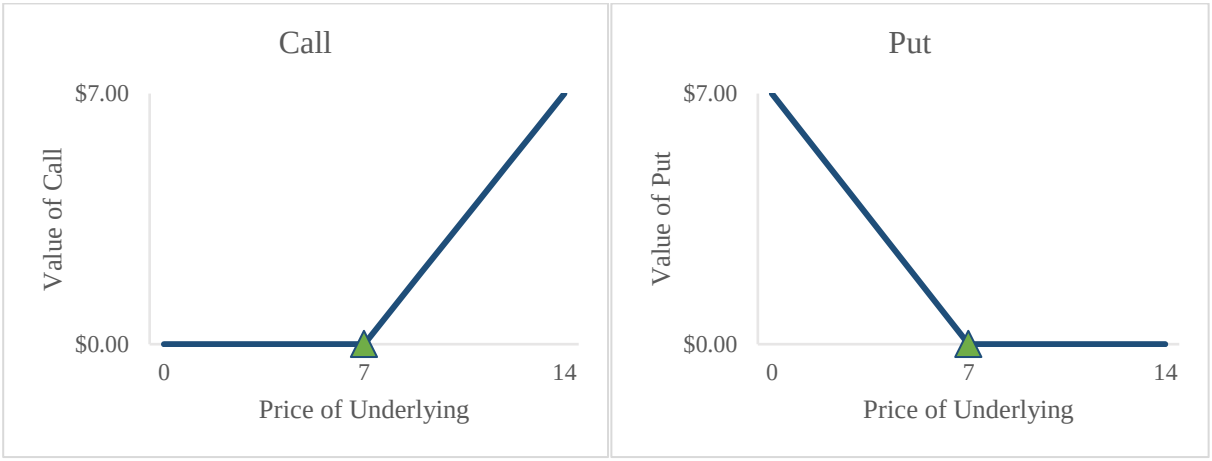
3. Hedging Strategies

Due to high uncertainty, the variety of factors influencing the coffee, and the volatility caused therefrom, it is vital for both producers and buyers to minimise their risk exposure to the fluctuating commodity spot price. Based on Taušer & Čajka (2016), three hedging techniques can be applied for agricultural commodity risk management. These include options, commodity forwards, and futures (Taušer & Čajka, 2016).

3.1 Options

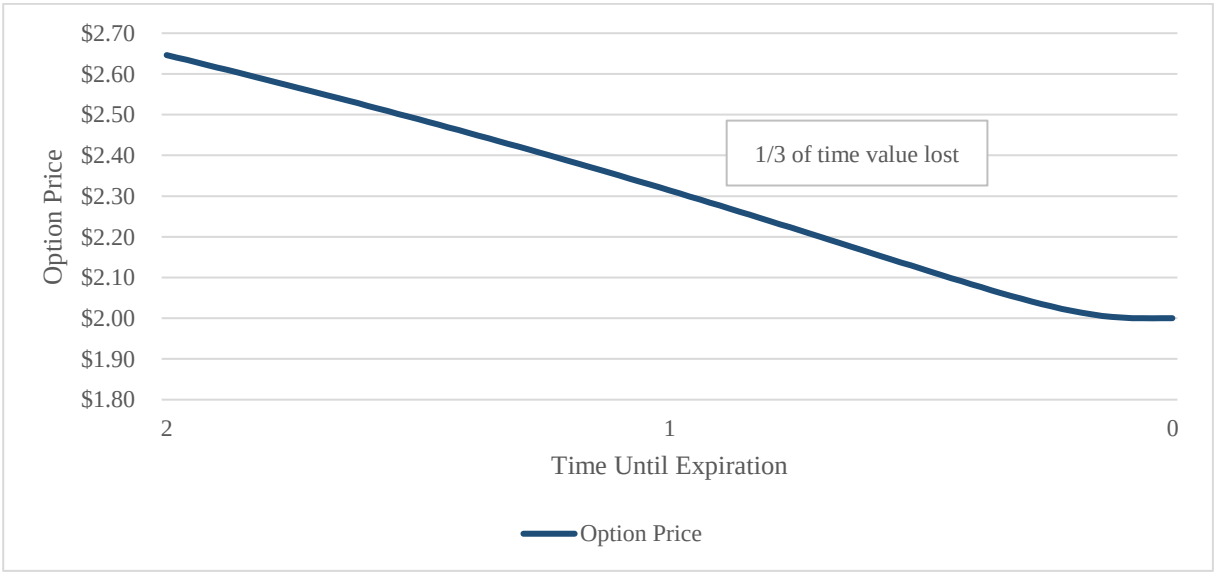
There are two types of options: call- and put options. Call (put) options give the right, but not the obligation, to buy (sell) the underlying asset at a predefined “strike price.” It can be distinguished between “American style” and “European style” options, the first being exercisable any time during the contract, the latter only at expiration. The most significant advantage of options is that downside risks can be hedged while still allowing to profit from favourable developments.

Figure 7: Visualisation Options



However, this comes at a price. The price of an option is made up of two factors, the intrinsic value of an option and its time value. The intrinsic value of an option is defined as the delta between its strike price and the price of the underlying. The option's time value is the result of the underlying's expected volatility and the time left until its expiration. So, an option with higher volatility and longer time until expiration has, ceteris paribus, a higher price. This is since the longer the option's lifespan, the more likely it is to end up in the money (meaning the option yields a profit when exercised). On average, options lose a third of their value in the first half of their lifespan, as visualised in figure 8 (Brealey et al, 2020, pp. 543-545).

Figure 8: Option Price Development[6]



[6] Based on the Black-Scholes formula with a price of the underlying of $7, an exercise price of $9, a risk-free rate of 0.05% and an annualised volatility of the coffee spot price of 32.29%

To calculate option prices for European type options, the Black-Scholes-formula[7] can be used. Apart from inherent characteristics of the option such as its kind and days until expiration, interest rates and the volatility of the underlying play a role in determining its price (MacBeth & Merville, 1979). Consequently, hedging coffee with options can become quite expensive due to the high historical volatility of the coffee spot price of 32.29% (σ) and an extended time horizon of the hedging due to the annual harvest interval of coffee.

Commodity options are usually non-deliverable, meaning that they are only financially settled. This way, producers and sellers can decouple their risk management from whom they decide to trade with, which allows for greater flexibility and efficiency in trade (Taušer & Čajka, 2016).

Options can be used in different ways for hedging. To showcase this, we introduce both a plain vanilla (only using one form of call or put option) and the "collar strategy" (using a set of options).

Plain Vanilla

Plain vanilla option strategies refer simply to using one kind of product only and no combination. In the context of commodities such as coffee, options can be used to acquire the right to sell or buy them at a specific price, thus mitigating price risk. Specifically, producers may buy put options to have the right to sell at a specific price, protecting them from a price decline. Buyers may buy call options to have the right to buy at a specific price, protecting them from price increases.

In a plain vanilla call strategy, buyers combine the amount they intend to buy and thus are short in, with put options. In a plain vanilla put strategy, sellers produce or buy the underlying and buy put options in corresponding amounts to the desired price. In our example, the buyer profits from prices below $7 and will not pay more than $7 for the coffee. This is inverse for the seller, who will not sell his commodity for a price lower than $7 and profit from prices higher than $7.

[7] See Appendix

Figure 9: Visualization Plain Vanilla Strategies



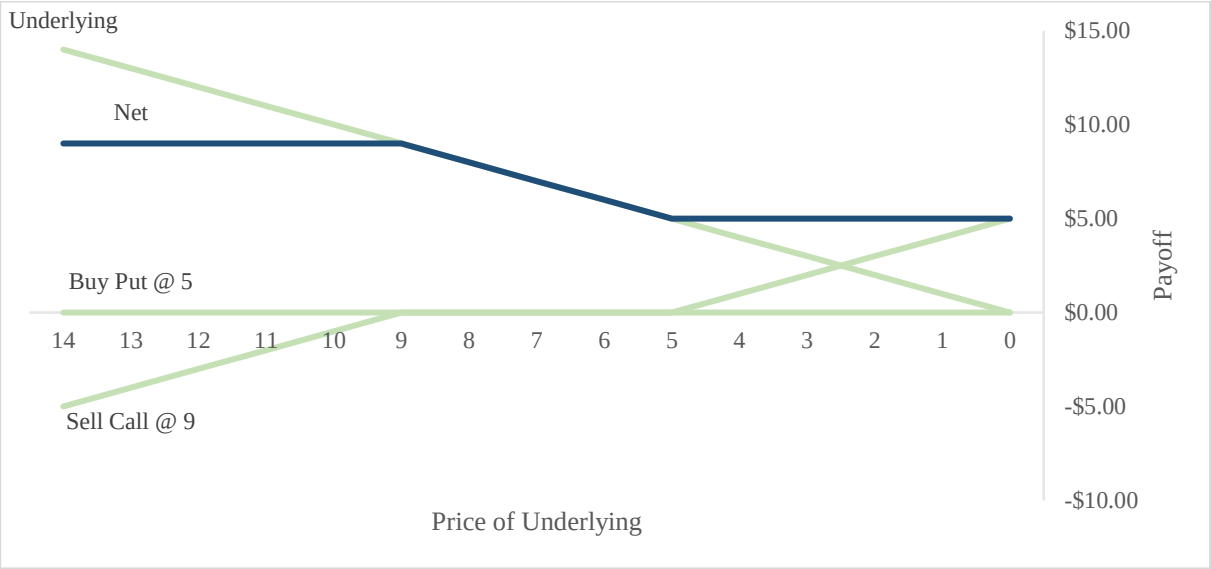
Subtracting the costs[8] of a call with a strike price of \$7, price of the underlying of \$7, and a time to maturity of 2 years, yields a net profit of $\$7 - \$1.27 = \$5.73$ if the prices stay the same. The same for a put strategy yields a net profit of $\$7 - \$1.26 = \$5.74$. This shows that the ability to profit from favourable price movements comes at a substantial price. To reduce the costs of using options, a variety of strategies can be used, one being the collar strategy.

Collar Strategy

In the collar strategy, a buyer or a seller can set boundaries to the price they would like to trade the commodity at. In the case of the buyer, one put option is sold, and one call option is bought. First, the call option with the desired strike price is bought, determining the upper bound for which the buyer will buy. In a second step, a put option, which constitutes the lower bound, will be sold. The strike price of the put is back solved by matching the price of the put option with the price of the call option. The matching prices constitute the advantage of this strategy, as it has net costs of zero.

[8] Calculated using Black-Scholes formula using parameters r_f= 0,05% and σ= 32.29%

Figure 10: Visualisation of buyer collar strategy

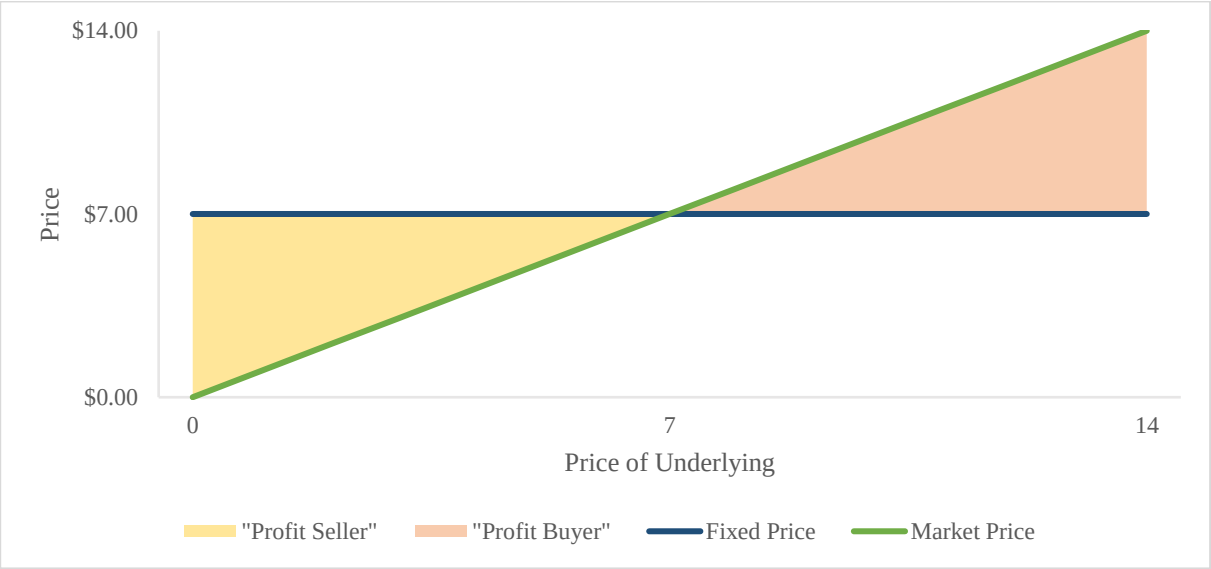


Using this strategy determines a “worst case” and “best case” price for the buyer, thus limiting both downside and upside “risk,” as opposed to only downside risk with the plain vanilla strategy. However, this strategy should be compared with forward and futures contracts, as their financial settlement may be more compelling when the future spot price is below the current spot price and vice versa (Taušer & Čajka, 2016, p. 180).

3.2 Forward Contracts & Futures

Forward contracts (“forwards”) are typically not traded on exchanges but rather over the counter (OTC) between two parties. They allow to "fix" a price on a specific date. Upon expiration, the closing price of the commodity is compared to the agreed forward price. The delta between both prices must then be paid by the party in the “disadvantageous” position. Hence, if the market price is over the agreed price, the buyer profits from the difference and vice versa. The buyer is practically in a long- and the seller in a short position. This way, the parties in a forward contract can hedge against all downside but also upside movements and thus "lock-in" a price. This decouples them entirely from market movements (Taušer & Čajka, 2016, pp. 177-178).

Figure 11: Visualisation Forwards and Futures



Futures are in many respects like forwards. The use of futures for commodity hedging has become increasingly popular in the past (Irwin & Sanders, 2012). A commodity futures contract represents an agreement to buy (sell) a specified quantity of a commodity at a specific futures date and specific price (Gorton & Rouwenhorst, 2006, p. 48). However, in comparison to forwards, they are standardised and thus tradable on exchanges, making them more accessible. Furthermore, forwards are settled once at the end of the contract duration, whereas futures are settled daily.

For buyers, hedging via forwards and futures is achieved by buying the number of securities equal to their (expected) need at the price they would like to "lock-in". Consequently, they are in a short position with their intent to buy and in a long position with their forwards and futures bought. They thus cancel each other out and allow the buyer to buy at a predetermined price.

The price of forwards and futures can be calculated as follows:

Equation 2: Forward & Futures Pricing Formula

$$F_t = S_t \cdot e^{(r_f+q)\cdot(T-t)}$$

With

F_t: Theoretical price of the contract

S_t: Spot price of the underlying

r_f: Risk-free rate

q: Carrying costs

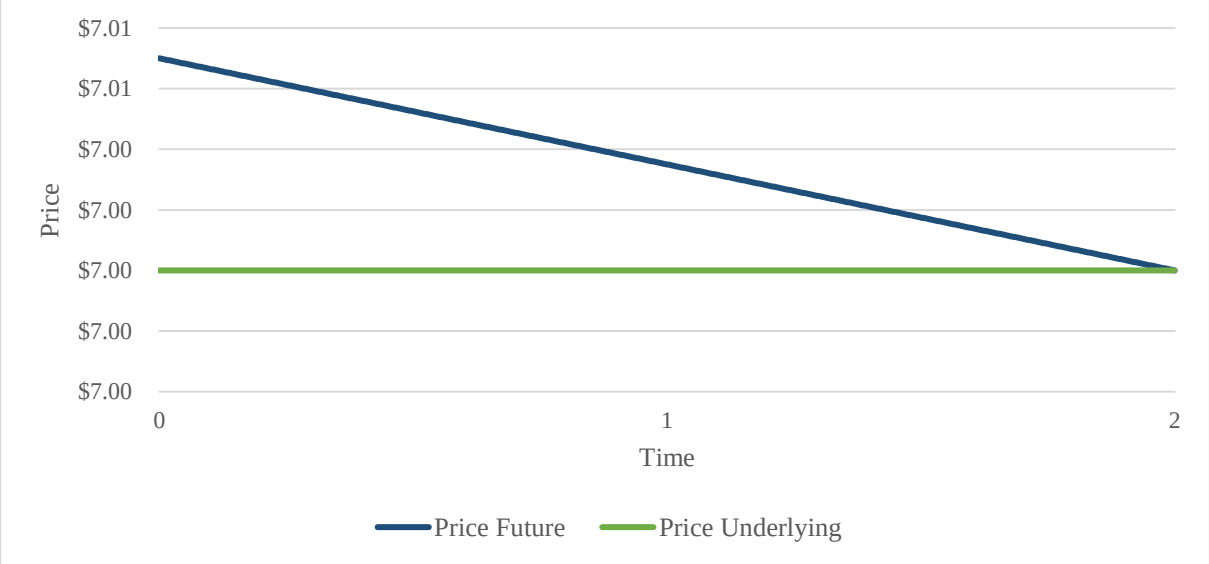
$(T - t)$: Time until contact maturity

This formula depicts the origin of the time value development, which is visualised in figure 12. Keeping the spot price constant, the value of the forwards and futures gradually decreases towards their maturity, similarly to options. Carrying costs in the formula only arise if the contract includes a physical settlement in the underlying asset. Carrying costs include the costs which stem from holding and storing the underlying, as well as delivering it to a specified location. In the case of non-deliverable contracts, these carrying costs can simply be disregarded.

In our example case, the price would be as follows:

$$F_t = \$7 \cdot e^{(0.05\%)\cdot(2)} = \$7.01$$

Figure 12: Forward and Futures Price Development



The main advantage of forward contracts lies in their ability to be tailored to individual needs, as opposed to standardised open market traded products. However, this advantage comes with the disadvantage that a suitable counterparty must be found to execute the desired agreement. This is, in turn, the advantage of futures, which are exchange-traded, as they trade in mostly liquid markets.

4. Applying the Hedging Strategies to Weather-based Price Developments

To demonstrate the impact of hedging coffee spot prices from a buyer's perspective, we choose Starbucks to exemplify how the strategies would translate into practice. Starbucks is a globally operating high-end roaster, marketer, and retailer of speciality coffee (Starbucks Corporation, 2020, p. 2). The company uses high-altitude Arabica coffee (the same that is primarily produced in Brazil). Starbucks is highly reliant on coffee as a commodity and thus dependent on its price. Hedging the risk arising from coffee spot prices is thus essential. Depending on market conditions, Starbucks uses a mix of fixed-price and price-to-be-fixed purchase commitments and derivative instruments such as forwards, futures, and collar hedges (Starbucks Corporation, 2020, p. 5).

Since Starbucks does not disclose how much coffee they buy annually, an estimation based on public information has to be made. According to Chad Moore (Starbucks Coffee Education Team), the proportion of coffee used by Starbucks is 10g of ground coffee for every 180ml (Starbucks, 2015). The Ohio State University estimates the amount of coffee-related beverages sold by Starbucks worldwide to be 2.3 billion in 2012 (OSU, 2021). Using the most commonly sold cup (450ml) as the average measurement (McRae, 2021), one can estimate how many millilitres of coffee Starbucks sold in 2012. Using the proportion proposed by Moore, it is possible to estimate how much coffee Starbucks used in 2012, which is 57,500 metric tons. After multiplying that value with Starbucks's revenue growth rate between 2020 and 2012, consumption of 101,679 metric tons of coffee in 2020 can be estimated for Starbucks.

4.1 Development of Likely Weather Scenarios and their Impact on the Spot Price

To demonstrate how our three proposed hedging approaches could work in practice, we use Starbucks' estimated coffee usage and apply the techniques to three possible weather scenarios in Brazil and their impact on the global coffee price. These weather scenarios are translated into spot prices using the regression from section 2. Each scenario spans from Q4 2020 to Q3 2021; thus, a period of four quarters or one entire harvest cycle. The Brazilian weather data applied covers 58 years, over which the variables prove to be normally distributed (using a Shapiro-Wilk-test). A normal distribution is also usually assumed for weather data (Baccon & Lunardi, 2016, p. 1). To avoid distortions in the standard variations, we simulate the unique quarters separately to account for seasonal differences, e.g., in rainfall and compile the scenarios at last. Weather indicators for each quarter are simulated 4,000 times; hence each scenario is based on 16,000 iterations. The base-case scenario extrapolates the Brazilian weather

development of the last 232 quarters one year into the future with the base year of 2019. The worst-case scenario uses the average of the worst Brazilian harvests (1975, 1977, 2001 (Shunev, 2021)) to simulate a slump in harvest volume in the main producing country. In contrast, the best-case scenario is built to depict an outstanding harvest period like in 1999, 2002 and 2018.

Figure 13, table 2 and table 3 depict the three weather simulations. Compared with the base-case scenario, Q1/2022 and Q2/2022 in the worst-case scenario are rainier, and the minimum and maximum temperatures only deviate a little (-3% to +1%). The best-case scenario, also compared with the base-case scenario, is characterised by lower-than-average precipitation in Q1-Q3/2022 and with higher minimum temperatures (+2% to +12%) and lower maximum temperatures (-7% to +1%) than average.

Moreover, coffee prices already show a gain of roughly 25% since the end of Q3 2021 due to the recent Brazilian harvest volume being dramatically lower (Shunev, 2021). Our worst-case scenario further proves to be in line with what walletinvestor.com (2021) predicts for the end of Q3 2022 (worst-case scenario $2.90, base-case scenario $2.50, best-case scenario $2.20), whereas our base-case and best-case scenarios appear to be more optimistic.

Table 2: Simulated Coffee Spot Prices for End of Q3 2022 by Scenario

		USD/lbs	Growth to Q3 2021
Price as of Q3 2021	$	1.94	-
Worst-case Scenario	$	2.96	52.33%
Base-case Scenario	$	2.10	8.25%
Best-case Scenario	$	1.70	-12.35%

Figure 13: Relative Deviation of Scenarios from 58-year Average by Quarter [9]



[9] Example for interpreting relative deviation: 1.2 means variable is 20% above the 58-average for this quarter.

Table 3: Simulated Weather Data and Relative Deviation to 58-year Average [9]

Average 58-years	Precipitation	Wind speed	Cloudiness	Minimum temperature	Maximum temperature	Relative humidity	Piche evaporation	Atmospheric pressure
Q4	4.37	2.15	5.70	19.92	30.57	70.71	4.44	965.23
Q1	6.33	1.83	6.05	20.51	30.46	76.02	3.32	965.27
Q2	3.67	1.72	5.00	17.87	28.41	75.40	3.13	967.65
Q3	1.90	2.13	4.31	16.81	28.85	67.48	4.73	968.82

Worst-case scenario	Precipitation	Wind speed	Cloudiness	Minimum temperature	Maximum temperature	Relative humidity	Piche evaporation	Atmospheric pressure
Q4/2021	3.83	2.04	5.21	19.47	30.58	69.25	4.69	964.10
Relative deviation	0.88	0.95	0.91	0.98	1.00	0.98	1.06	1.00
Q1/2022	7.86	1.67	5.57	19.92	29.98	76.40	3.07	965.46
Relative deviation	1.24	0.91	0.92	0.97	0.98	1.00	0.93	1.00
Q2/2022	4.05	1.58	4.46	17.51	28.39	74.26	3.07	967.93
Relative deviation	1.11	0.92	0.89	0.98	1.00	0.98	0.98	1.00
Q3/2022	1.61	1.97	3.62	16.39	29.05	65.25	4.96	968.63
Relative deviation	0.85	0.93	0.84	0.98	1.01	0.97	1.05	1.00

Base-case scenario	Precipitation	Wind speed	Cloudiness	Minimum temperature	Maximum temperature	Relative humidity	Piche evaporation	Atmospheric pressure
Q4/2021	4.27	2.33	5.92	21.22	31.48	66.35	4.25	966.44
Relative deviation	0.98	1.09	1.04	1.07	1.03	0.94	0.96	1.00
Q1/2022	6.63	1.79	6.27	22.27	31.32	75.45	3.03	971.45
Relative deviation	1.05	0.98	1.04	1.09	1.03	0.99	0.91	1.01
Q2/2022	3.89	1.75	5.27	18.95	29.36	75.10	2.69	971.97
Relative deviation	1.06	1.01	1.05	1.06	1.03	1.00	0.86	1.00
Q3/2022	1.87	2.19	4.50	18.30	29.23	62.66	4.30	969.15
Relative deviation	0.99	1.03	1.04	1.09	1.01	0.93	0.91	1.00

Best-case scenario	Precipitation	Wind speed	Cloudiness	Minimum temperature	Maximum temperature	Relative humidity	Piche evaporation	Atmospheric pressure
Q4/2021	4.38	2.27	5.81	22.36	29.93	66.71	4.32	962.67
Relative deviation	1.00	1.06	1.02	1.12	0.98	0.94	0.97	1.00
Q1/2022	5.75	1.87	6.56	20.96	28.34	72.18	3.60	967.36
Relative deviation	0.91	1.02	1.08	1.02	0.93	0.95	1.08	1.00
Q2/2022	3.38	1.72	5.54	18.79	27.78	71.99	3.84	973.68
Relative deviation	0.92	1.00	1.11	1.05	0.98	0.95	1.23	1.01
Q3/2022	1.63	2.38	4.36	17.70	29.14	59.52	4.74	970.41
Relative deviation	0.86	1.12	1.01	1.05	1.01	0.88	1.00	1.00

4.2 Performance of the Strategies in each Scenario

Collar Strategy

For the collar strategy, we aim to protect ourselves against a price increase of more than 10%. The estimated input parameters for the Black-Scholes option pricing model allow for profiting from a downward price movement of up to 7%. In absolute terms, the price we pay per pound would thus be locked in between a maximum of $2.13 and a minimum of $1.80. We thus buy a call option with a strike price of $2.13 at a price of $0.18 and sell a put option with a strike price of $1.80 for $0.18. Our net hedging costs are consequently zero, as the option prices match. For the estimated 101,677 tons of coffee, we need to buy 224,161,247 call options and sell the same amount of put options.

Table 4: Results of Collar Strategy by Scenario

	Worst-Case	Base-Case	Best-Case
t=1 Price	$ 2.96	$ 2.10	$ 1.70
Profit/Loss from Call bought	$ -0.83	$ -	$ -
Profit/Loss from Put sold	$ -	$ -	$ 0.10
Net Buying price	$ 2.13	$ 2.10	$ 1.80
Net "Profit"	$ 0.83	$ -	$ -0.10
Net Buying price (Total)	$ 478,360,100.97	$ 470,738,618.58	$ 403,854,187.27
Net "Profit" (Total)	$ 185,157,189.97	$ -	$ -22,780,067.47
Cost of Call	$ 39,408,599.88	$ 39,408,599.88	$ 39,408,599.88
Cost of Put	$ -39,408,599.88	$ -39,408,599.88	$ -39,408,599.88
Net Cost	$ -	$ -	$ -

In the worst-case scenario, we manage to buy the coffee at our max boundary of $2.13 instead of $2.96, which saves us more than $185m. In the base-case scenario, the ending price is within our boundaries, which is why we buy at the market price of $2.10 without benefitting from the options. In the best-case scenario, the ending price is below our minimum boundary, forcing us to buy for the higher price of $1.80, which “costs” us roughly $22.8m more than without hedging.

Forward & Future Strategy

In all three scenarios, we lock in the price at our starting price of $1.94. As with the other strategy, we buy 224,161,247 units of the instruments as this corresponds to the amount of lb we intend to hedge. Using the forward and futures pricing formula without carrying costs,

this comes with a cost of $222{,}161{,}247 \cdot \$1.94 \cdot e^{(0.05\% \cdot 1)} = \$217{,}490.78$ in each scenario. In the worst-case scenario, with a price of $2.96, we would still be able to buy at a price of $1.94 ("profit" of $1.02 per instrument). Subtracting the costs of buying futures translates to savings of over $228m in total. In the base-case scenario, with a price of $2.10, we would still profit from our lock-in price at $1.94 ("savings" of $0.16 per future). Subtracting the buying costs translates into cost savings of more than $35m. However, in the best-case scenario with a price of $1.70, our strategy turns against us. As we are forced to buy at a price of $1.94, we incur a loss of $0.24 per future, which translates into overall additional buying costs of more than $54m.

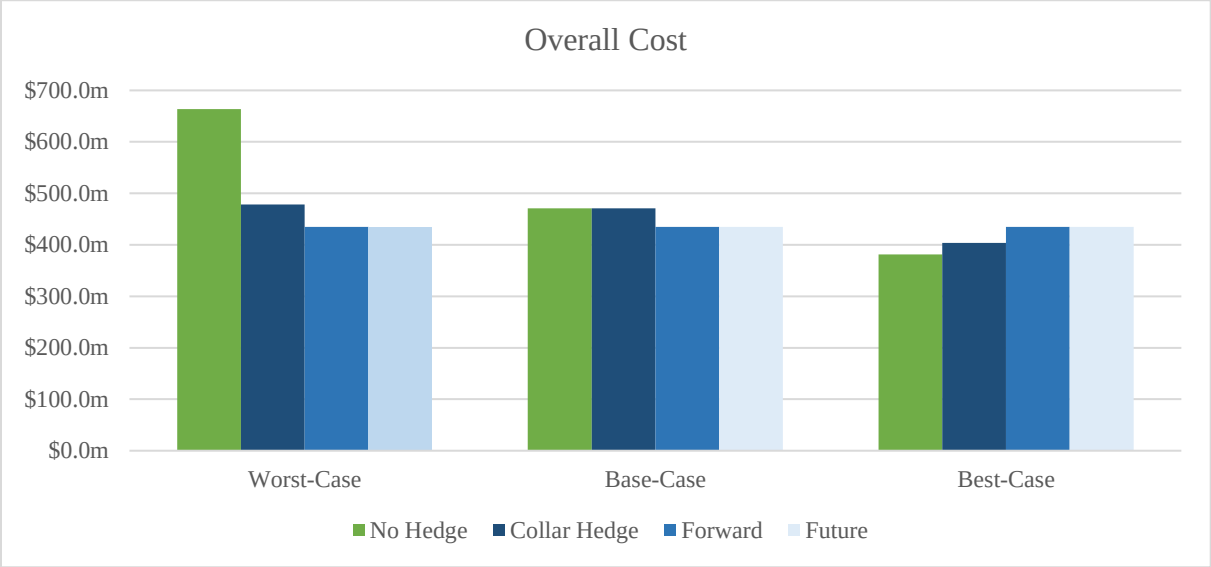
Table 5: Results of Forwards and Futures by Scenario

	Worst-Case	Base-Case	Best-Case
Beginning Price	$ 1.94	$ 1.94	$ 1.94
Ending Price	$ 2.96	$ 2.10	$ 1.70
Fixed Price	$ 1.94	$ 1.94	$ 1.94
Forward Price	$ 1.94	$ 1.94	$ 1.94
Net Buying price	$ 1.94	$ 1.94	$ 1.94
Net "Profit"	$ 1.02	$ 0.16	$ -0.24
Net Buying price (Total)	$ 435,090,309.84	$ 435,090,309.84	$ 435,090,309.84
Net "Profit" (Total)	$ 228,426,981.10	$ 35,648,308.73	$ -54,016,190.04
Cost	$ 217,490.78	$ 217,490.78	$ 217,490.78

4.3 Summary of the Hedging Strategies' Performance

The hedging strategies perform differently well depending on which scenario they are applied to. In the worst-case scenario of a 52.3% price increase, all strategies effectively protect us from paying the higher price, while forwards and futures perform slightly better than the collar strategy. In the base case scenario of an 8.3% price increase, the collar strategy equals the price we would pay without hedging, whereas the forward and future strategies fully protect us from the price increase. In the best-case scenario of prices dropping 12%, the collar strategy allows us to profit from this decline up to our lower price boundary, whereas the cost of the forward and future strategy remain locked in at our specified price, resulting in paying a higher price than the market spot price.

Figure 14: Overall Cost of Coffee by Scenario



Overall, the strategies have different advantages and disadvantages, and some generate favourable results based on the development of the underlying. It thus makes sense, as many companies, including Starbucks, are already doing it, to mix the methods to generate a good result in all kinds of scenarios.

Table 6: Overall Cost, Profit and Cost of Hedging

		No Hedge	Collar Hedge	Forward	Future
Overall Cost	**Worst-Case**	$ 663,517,290.95	$ 478,360,100.97	$ 435,090,309.84	$ 435,090,309.84
	Base-Case	$ 470,738,618.58	$ 470,738,618.58	$ 435,090,309.84	$ 435,090,309.84
	Best-Case	$ 381,074,119.80	$ 403,854,187.27	$ 435,090,309.84	$ 435,090,309.84
	Average	$ 505,110,009.77	$ 450,984,302.27	$ 435,090,309.84	$ 435,090,309.84
	Standard deviation	23.3%	7.4%	0.0%	0.0%

		No Hedge	Collar Hedge	Forward	Future
Profit	**Worst-Case**	$ -	$ 185,157,189.97	$ 228,426,981.10	$ 228,426,981.10
	Base-Case	$ -	$ -	$ 35,648,308.73	$ 35,648,308.73
	Best-Case	$ -	$ -22,780,067.47	$ -54,016,190.04	$ -54,016,190.04
	Average	$ -	$ 54,125,707.50	$ 70,019,699.93	$ 70,019,699.93
	Standard deviation	n.m.	172.0%	168.3%	168.3%

		No Hedge	Collar Hedge	Forward	Future
Cost of hedging	**Worst-Case**	$ -	$ -	$ 217,490.78	$ 217,490.78
	Base-Case	$ -	$ -	$ 217,490.78	$ 217,490.78
	Best-Case	$ -	$ -	$ 217,490.78	$ 217,490.78
	Average	$ -	$ -	$ 217,490.78	$ 217,490.78
	Standard deviation	n.m.	n.m.	0.0%	0.0%

5. Conclusion

In summary, the regressions show that only 17% of the movements in the coffee spot price are attributable to changes in demand and supply and only 14% can be explained with weather in the main Brazilian cultivation area. The high volatility in the commodities price proves to stem from various sources, with none of them causing it by an unproportionally large extent. Therefore, hedging only one of them would not entirely eliminate the price risk. Hedging all of them individually is not only complicated but also inefficient. Consequently, it makes more sense to hedge against the price risk itself. Our case analysis shows that a combination of the most commonly used hedging approaches, namely options-, forwards-, and futures strategies yield the best results, and should thus preferably not be used in isolation.

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7. Appendix

Equation 3: Black-Scholes Model

$$C = S_t N(d_1) - Ke^{-rt} N(d_2)$$

With:

$$d_1 = \frac{ln\frac{St}{K} + \left(r + \frac{\sigma_v^2}{2}\right)t}{\sigma_S\sqrt{t}}$$

$$d_2 = d_1 - \sigma_S\sqrt{t}$$

$$C = Call\ option\ price$$

$$S = Current\ underlying\ price$$

$$K = Strike\ price$$

$$r = Risk - free\ interest\ rate$$

$$t = Time\ to\ maturity$$

$$N = Normal\ distribution$$

$$\sigma_S = Volatility\ of\ the\ underlying\ asset$$